OUTFITTING AND OPERATIONS
OF THE U. S. SPACE STATION LABORATORY

by

Gordon R. Woodcock
Boeing Aerospace Company
Huntsville, Alabama

INTRODUCTION

Materials science research in the absence of gravitational forces, under microgravity conditions, is one of the unique opportunities available in space. The absence of gravitation poses both design problems and research promise; this was recognized from the beginning of our space program. Exploratory experiments were carried out on a few of the Apollo missions. The beginnings of organized research occurred on the Skylab space station missions, and further experiments were conducted on the Apollo-Soyuz mission. The advent of Shuttle brought opportunity for microgravity experiments in the cabin middeck, in Getaway Special cannisters, on payload carriers in the Shuttle payload bay, and in the Spacelab. The Soviet space program has seen extensive microgravity research aboard the Salyut series of space stations. Some Soviet watchers believe the new, larger Mir station will be largely devoted to pilot production of electro-optical materials.

Microgravity research has advanced from exploratory experiments to structured research and development in a few years. Work in the field, however, is presently severely constrained by access to the space environment. Imagine the frustration of trying to conduct materials laboratory research and development if one could use one's lab only one week out of every year. That is approximately the contraint under which Western microgravity research is conducted (the Soviets enjoy more or less continuous operation of their facilities, but access, i.e. resupply or return opportunities, are infrequent). The U. S. space station will, for the first time, offer researchers and commercial developers a continuously available, continuously manned facility with something approximating reasonable access in the form of a shuttle visit about every six weeks. This represents an increase in facility availability on the order of fifty and is expected to greatly stimulate research and development progress. It will, for example, be possible to complete the development of a commercial process in a time period short enough to attract investors. Research and development programs, rather than isolated experiments, will be the norm.

The space station promises an entirely new and highly productive way of doing microgravity R & D in space. This promise can be transformed into reality *if* the space station designers create the right kind of laboratory design and operating environment. That challenge and what we on the space station program are doing about it is the subject of this paper.

(NASA-CR-182307) OUTFITTING AND OPERATIONS OF THE US SPACE STATION LABORATORY (Boeing Aerospace Co.) 38 p Avail: NTIS
N88-70063
Unclas
00/18 0114145

Laboratory Operations

The space station laboratory must have new kinds of design features to enable its new way of operating. To specify these new design features, we must take care to properly understand the new way of operating. A beginning is to compare the space station lab with the present Spacelab, as in Table 1.

Preparation of the Spacelab for flight is a time-consuming operation. (This is not intended as a criticism since the Spacelab has the luxury of time and the labor-intensive integration and checkout procedure simplified the design.) Experiment payloads are built up in standard racks and checked out. Software is written for the Spacelab computer with a flow time of about eighteen months. The entire payload assembly is integrated and checked out in the KSC Spacelab facility before installation; the end caps of the Spacelab are removable so that the completed assembly can be end-loaded into the Spacelab shell. Once the assembly, integration and checkout are completed, the Spacelab is installed in the Shuttle payload bay (in the Orbiter Processing Facility), connected to the Shuttle cabin by the Spacelab tunnel, and integrated with the Shuttle. The Shuttle supplies electrical power, thermal control, partial environmental control, and communications for the Spacelab; integration and checkout must ensure that all interfaces are made and functioning properly.

Several weeks normally transpire between the time the Spacelab is loaded into the Shuttle and the actual launch. Late access to the Spacelab, for example to place living specimens onboard, is accomplished through the Shuttle cabin and the Spacelab tunnel on the pad, using an apparatus like a bosun's chair.

The Spacelab operates basically as an experiment carrier. While there is extensive crew involvement in experiment operations, the short duration of the Spacelab flights means that most experiment preparations and analysis of results should be, and are, conducted on the ground. Crew presence and involvement in Spacelab has proven of inestimable value in troubleshooting and repairing experiments, as well as in interpreting results and exchanging information with scientists on the ground that would be missed if, for example, the experiments were automated and operated remotely in the Shuttle payload bay.

The space station laboratory will not return to Earth for experiment installation and integration; these functions will be accomplished in space. Because of the quantum leap in flight opportunity time and the long duration onboard residency afforded by the space station's permanence, operations in the space station lab will be attuned to research and development programs rather than isolated experiments.

After its initial assembly, integration and checkout on the ground prior to launch, the space station lab will be, for all practical purposes, permanent in space. Experimental equipment and facilities will be built up, usually but not necessarily

Table 1

US Lab vs Present Capabilities

	SPACELAB	US LAB
CREW TIME	28 MAN DAYS MISSION 84 MAN DAYS/YR STARTING IN 1988	1020 MAN DAYS/YR STARTING IN 1994
POWER	7 kw AVERAGE	18.6 kw AVERAGE WITH GROWTH TO 25-50 kw
RACK VOLUME	10 SPACELAB DOUBLE RACKS	22 STATION DOUBLE RACKS
MICRO g	10^{-6} g	10^{-6} g
PROCESS CALIBRATION	LIMITED TO EXTREMELY SIMPLE CHARACTER EQT. AND VERY BENIGN SAMPLES	MUCH BROADER RANGE OF EQT. AND SAMPLE TYPES
EXPERIMENT REFLIGHT OPPORTUNITIES	LESS THAN ONCE A YEAR	CONTINUOUS

The US LAB will provide more power, volume, operations flexibility, and crewtime than present capabilities

always, into racks similar in size to Spacelab racks, pre-integrated in simulator/emulator facilities on the ground, and entered into the space station logistics system. Lab equipment will ordinarily be launched in a logistics module aboard the shuttle. This module is about the size of Spacelab; it is designed to be berthed to the space station so that equipment can be transferred into the space station in a shirt-sleeve pressurized environment. The logistics module is not connected to the Shuttle cabin by a tunnel. Means of late access for perishable scientific payloads have not been selected, but the most likely candidate is a hatch to permit entry through the Shuttle payload bay before the payload bay doors are closed. Small payloads could be carried in the Shuttle cabin since it, as well as the logistics module, will be berthed to the space station.

When a laboratory payload rack arrives at the space station, it will be transported to the lab. Unlike Spacelab with its removable end cone, all equipment for the space station lab must pass through the hatchway; its dimensions, and those of the standard payload envelope "~~double rack~~", are shown in Figure 1. Payloads too large to pass through the hatch will have to be built up inside the lab.

Rack installation design is aimed at making the installation and checkout job simple. The rack is placed into its location, with structural fasteners accessible from the front. All connections to the rack are fully accessible from the front as depicted in Figure 2, so that interface verification is accomplished with the rack in its operating position and with the working rack front accessible. An alternate "tilt-out" scheme shown in Figure 3 would permit access to the sides and rear of the rack without disconnecting the hookups, but with the face inaccessible it reminds this author of working on a TV set without being able to see the picture. Since access to all sides of a rack while it is connected to utilities will sometimes be necessary, an arrangement permitting the rack to be slid out with extender cables seems appropriate.

Individual process runs (i.e. "experiments"; our experiment-oriented experience with this immature field leads us to label any process run as an "experiment") will take from a few minutes to about three weeks. Clearly, effective use of a permanently orbiting lab requires that we be able to repeat runs, assess results, modify, and continue investigations with on-orbit resources. This means preparation or exchange of samples, calibration and setup, real-time monitoring, cleaning of apparatus and equipment to prepare for additional runs, quick-look analysis, and modification and repair of equipment, and it means that the support equipment for these functions must be present in the laboratory. Our early perceptions of lab operations supposed a relatively complete analytical laboratory on orbit, but it soon became clear that the 200-to-1 ratio of on-orbit to on-the-ground cost of a research manhour meant that only quick-look analysis essential to timely continuation of an investigation should be performed in space.

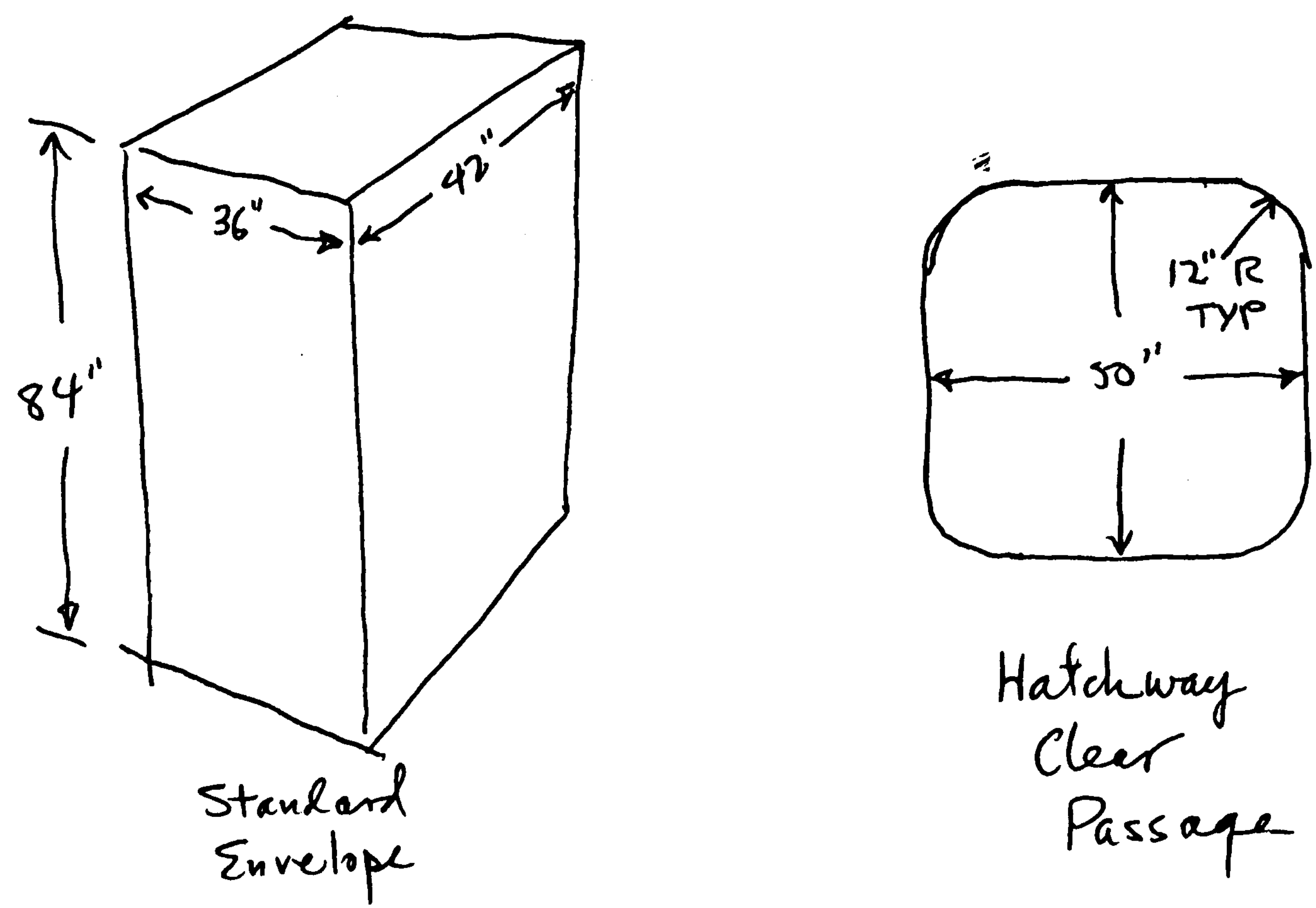


Figure 1. Standard Envelope and Hatch Dimensions

Figure 2 Preferred Gas Line Routing

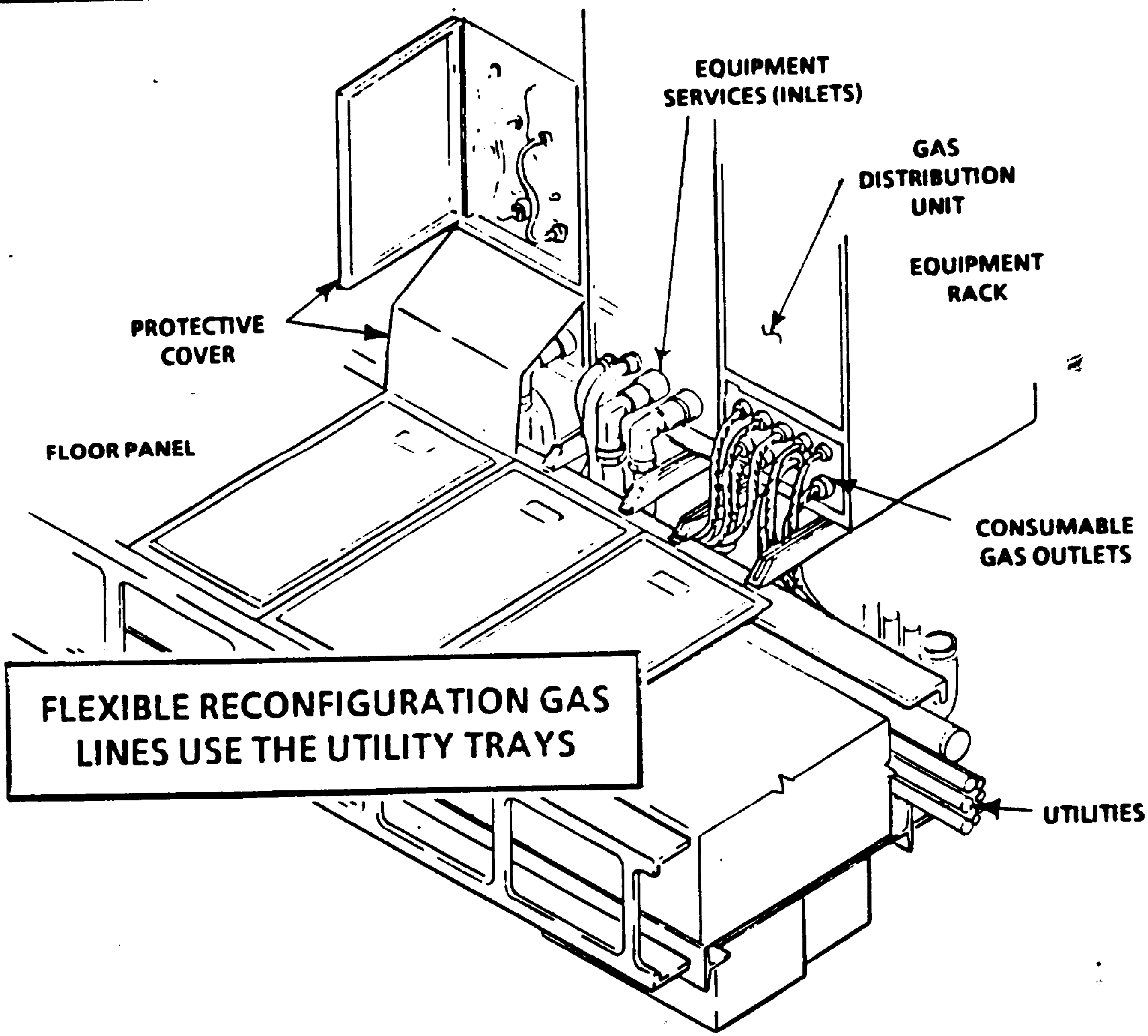
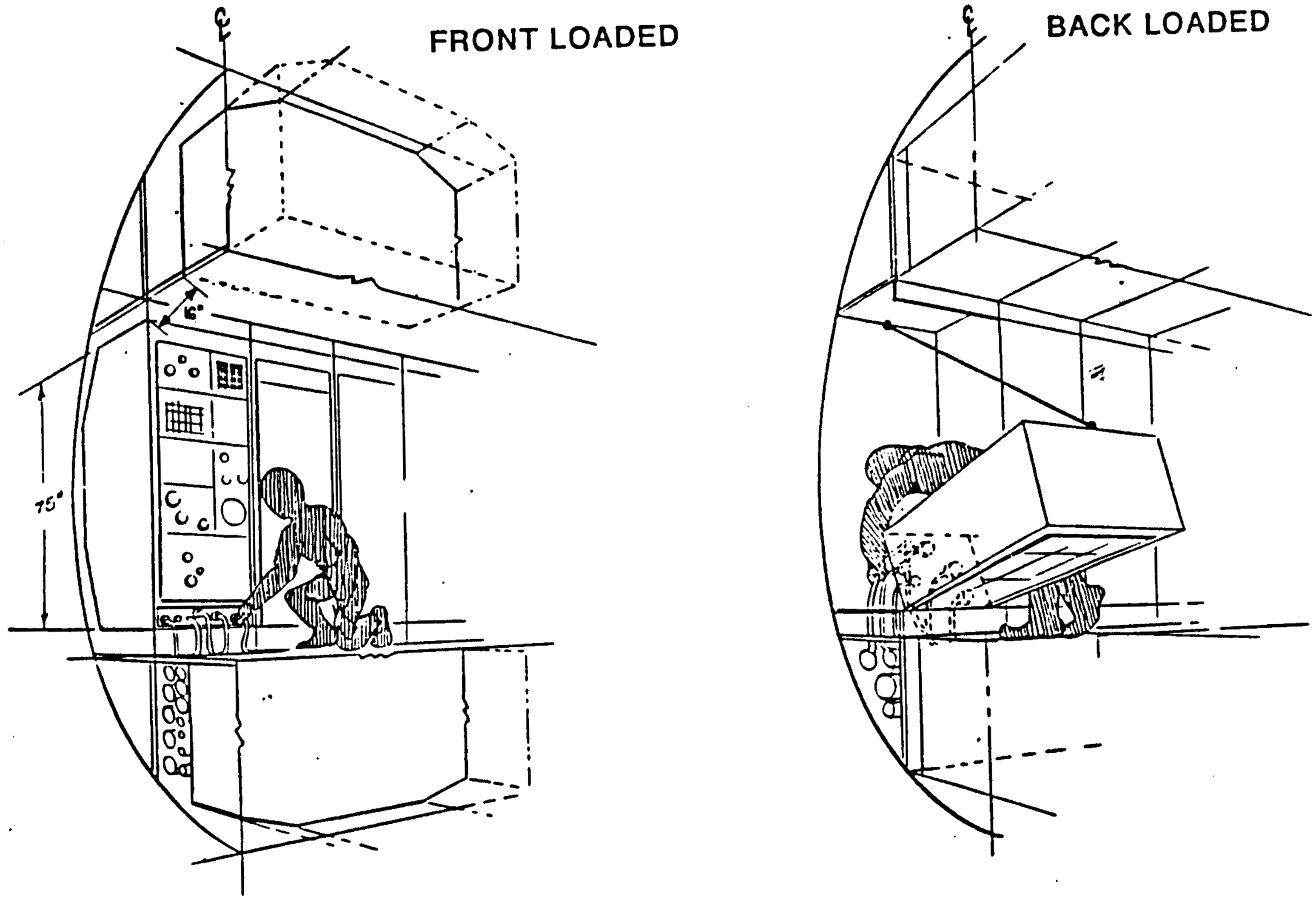


Figure 3

Utility Plumbing to Racks



FRONT LOADED UTILITIES ARE THE PREFERRED CONCEPT

The intensity of use of laboratory equipment is a key issue. If all the equipment in the lab were in use all the time, we would need over a hundred kilowatts to power it and more than the entire space station crew to operate it. However, analysis equipment will be operating only when analysis is done, and experimental payloads will be dormant part of the time because its users will be occupied with in-depth analysis and planning or redesign of further investigations.

We looked into the intensity of using typical payloads through scenario anlayses. These depicted research and developmental programs and their uncertainties. Figure 4 is a flow diagram of one of these scenarios. Each block represents a series of process runs or an activity that must be completed before process runs can resume. Each is characterized by a calendar time and, where appropriate, by resupply requirements. Branches represent uncertainties, "what-ifs", where relative success or failure cannot be accurately predicted and affects continuation of the investigation. Scenarios were processed by a simple permutation-combination computer routine.

Results for the scenario described above are shown in Figures 5 and 6. The "S" shape of the total elapsed time curve indicates that the scenario included enough branches for representative overall statistics (it shows that the joint distribution approaches a normal distribution). The time required, in this example, to reach a commercialization decision is within a typical investment horizon. The key point for laboratory design is that the lab payload is in use about 35% of the time. This was representative for all our scenarios; the result was used in resource (power, etc.) analyses described below. A second important finding is that the lab should accommodate more payloads than the available crew can operate simultaneously because payloads will be inactive most of the time. The cost of transporting payloads up and down is so high that it will be economical for a customer to pay space station occupancy charges during usual dormant periods.

The Man-Tended Option

The space station program presently includes a man-tended option. This option is investigated both as a principal option, i.e. something to exist for several years, and as an interim option, a step in the space station buildup process to exist for a few months up to perhaps a year. The man-tended lab would be operated remotely by automation or teleoperation except during shuttle visits, typically six per year, with about seven days of productive crew time each.

We found that process runs can, in most cases, be readily automated (and will be also for the permanently manned lab to conserve crew time) but that such things as sample preparation and equipment clean-up are beyond the planned state of the art for robotics during the early space station years. Teleoperation is a possibility; we developed concepts such as depicted in

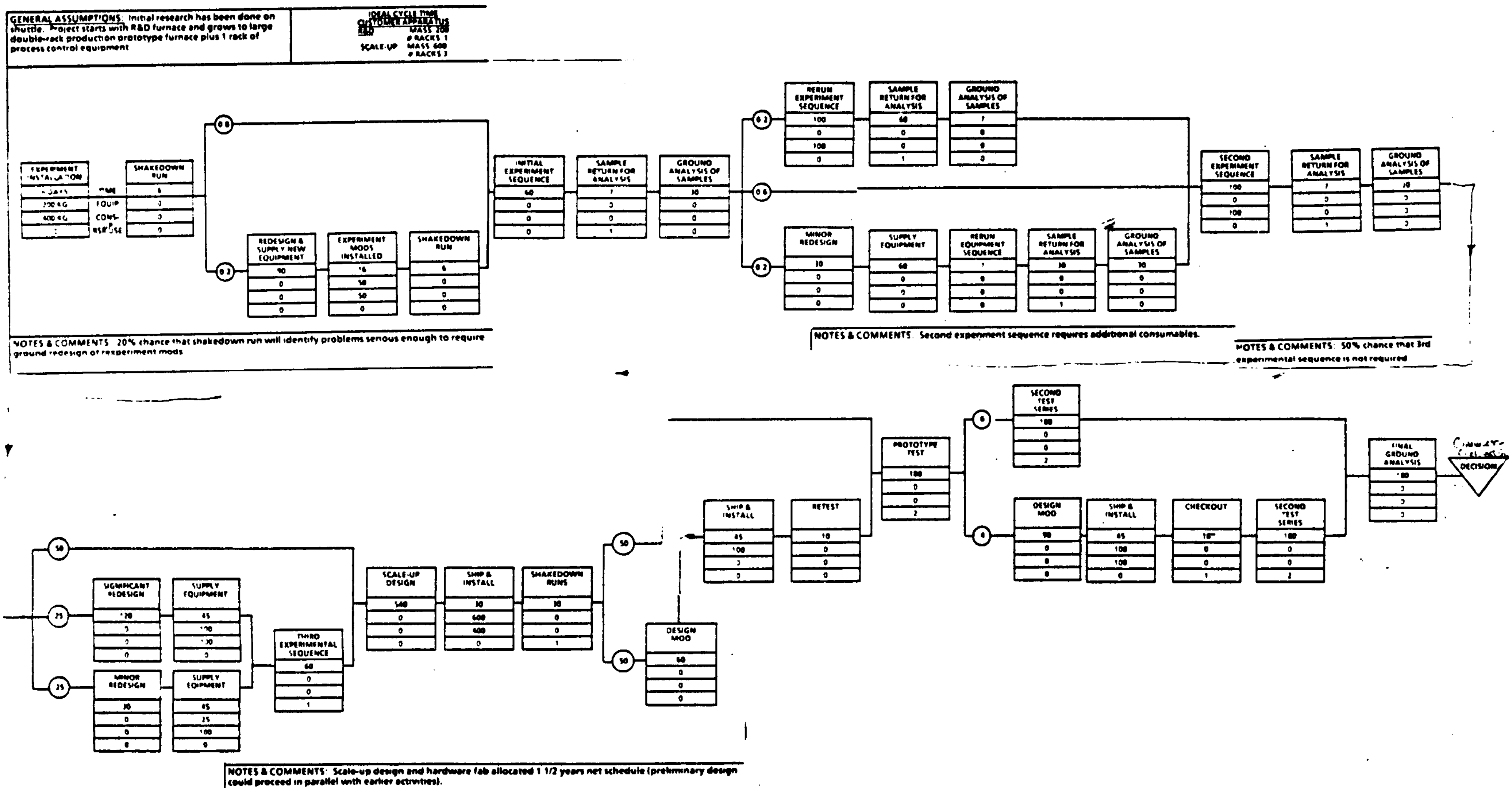
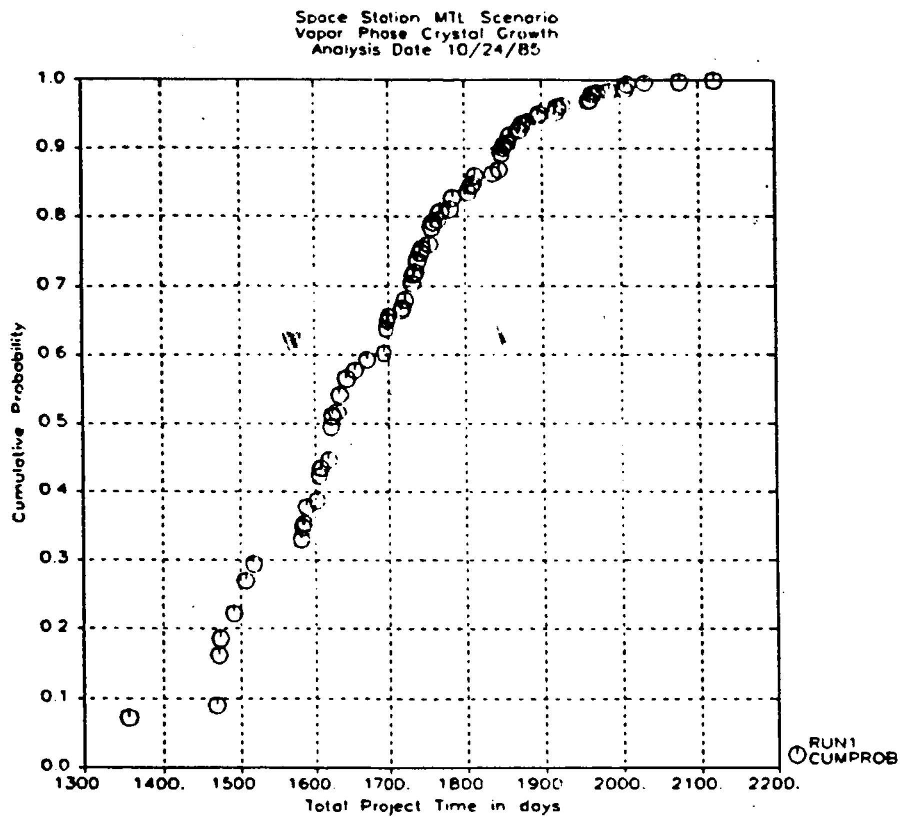


Figure 4 – Scenario For Development of Commercial Vapor Phase Crystal Growth Process



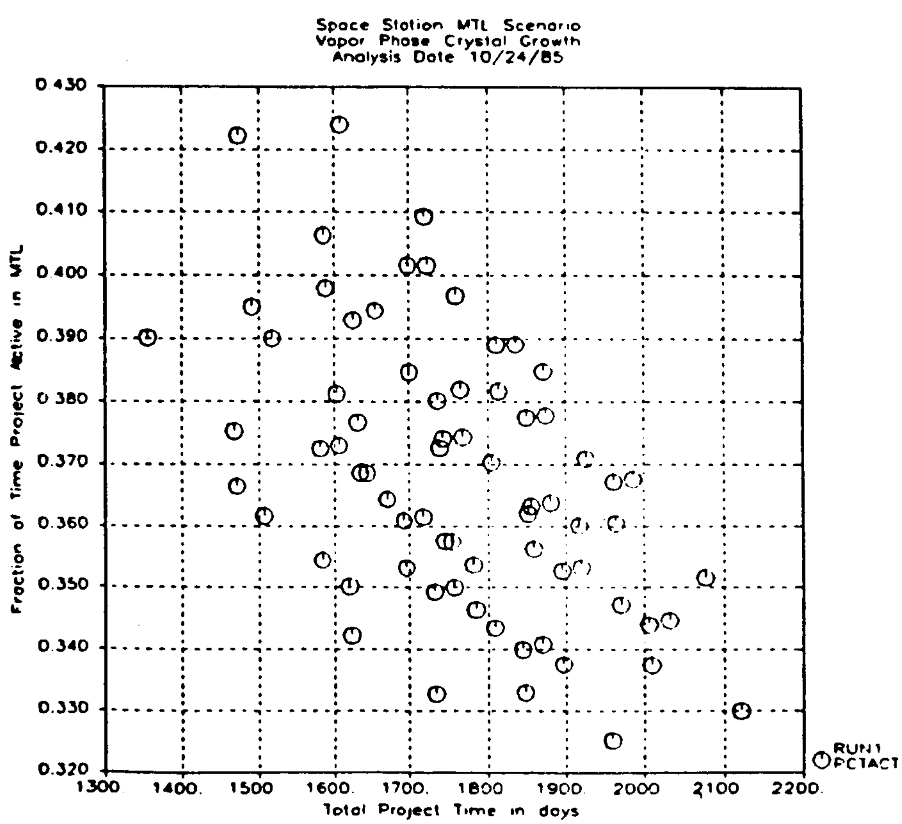
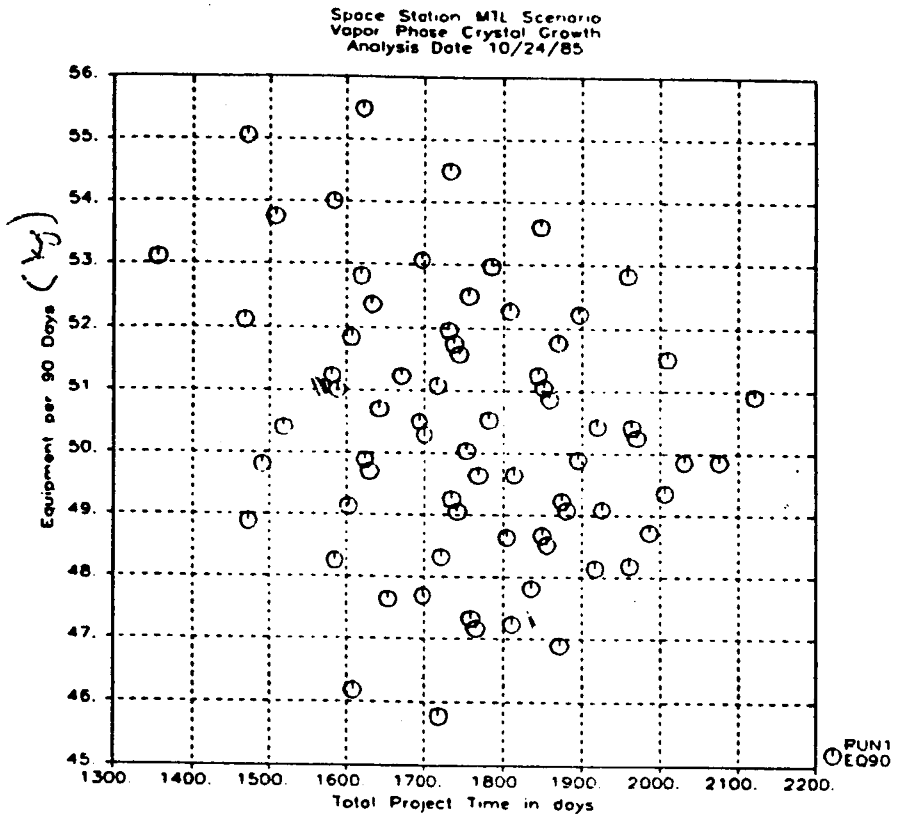


Figure 5 - Scenario Flow Results



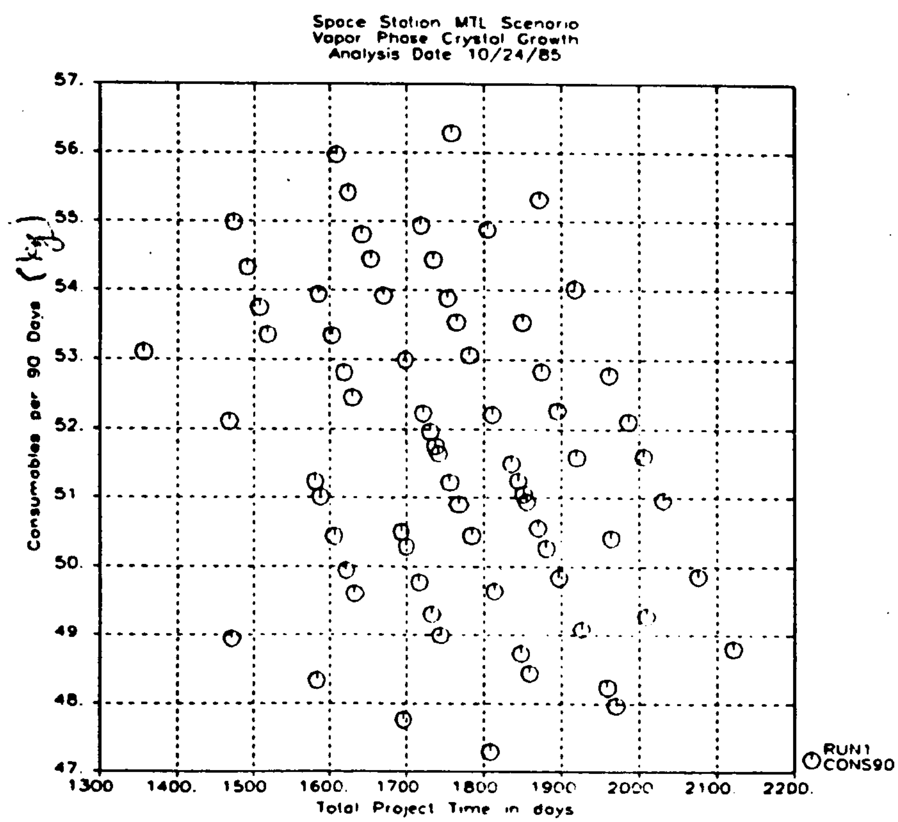


Figure 6 - Scenario Flow k ...ts, Continued

Figure 7 for a "human emulator". The communications time delay for space station can be up to several seconds because of processing and multiple passes through geosynchronous satellites; this poses severe problems for teleoperation.

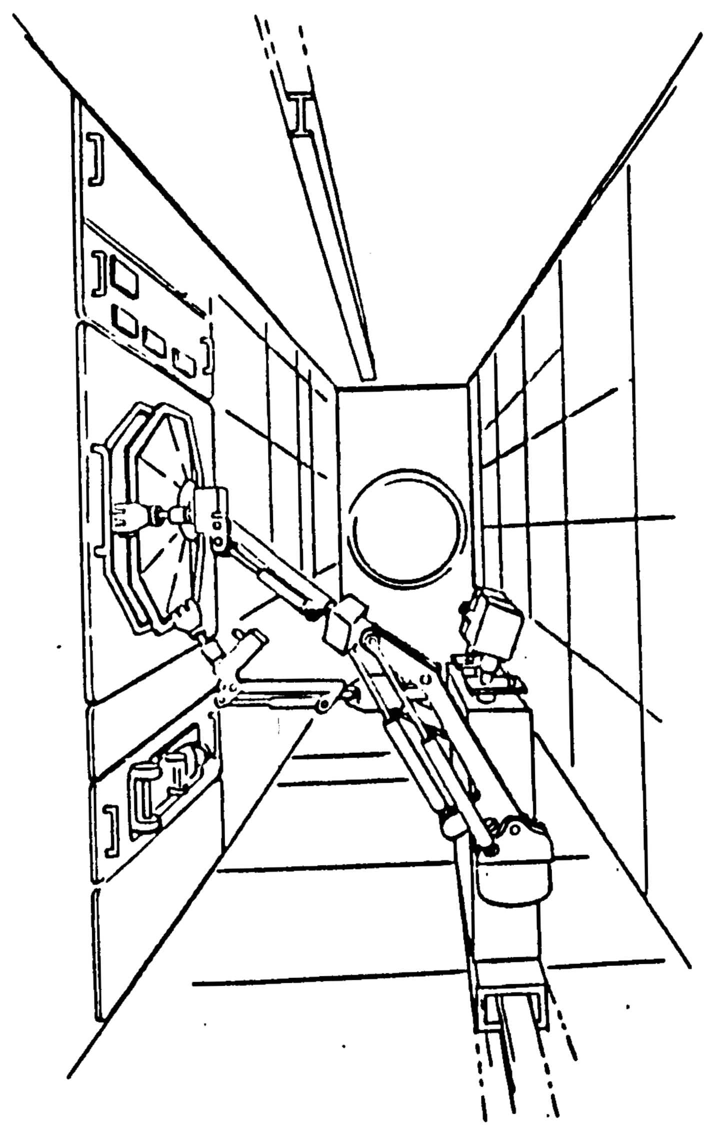
The upshot of the man-tended investigation was that (1) the loss in productivity, compared to the permanently manned option, is entirely out of proportion to the relatively modest cost savings for a semi-permanent man-tended option; (2) interim man-tended operations during space station buildup offer a significant increase in facility availability over current capabilities and makes good sense. Investment in special equipment to enhance man-tended operations for a short time period is not warranted.

SPACE STATION

Figure 7

Teleoperated Human Emulator for MTL Applications

BOEING



Missions And Station Accommodations Test Sets

Mission requirements have been emphasized in the space station program since before it was a program. In 1982, NASA undertook a set of eight contractor studies of space station mission needs and architecture. Configuration concepts were specifically discouraged in order to force emphasis on mission needs. Much effort was devoted to contacting potential users of a space station, and while some became more than a little annoyed at being contacted by eight study teams, a substantial data base was collected and reported to NASA. The Langley Research Center was the focal point for data base compilation, review, and analysis. After a period of review, critique and revision by NASA and its contractors, led by advocacy teams for each major mission category, this mission data base was formalized as the "Langley Data Base" and it became the baseline for space station mission requirements analysis. Accommodation of all the missions in the data base by the intital space station is out of the question; NASA has abstracted from the entire data base several representative mission groupings called "station accommodations test sets"; SATS. In this data base and these test sets the space station materials processing lab is designated COMM 1201, and two potential early commercial manufacturing payloads are designated as COMM 1202 and COMM 1203. The present U. S. space station laboratory includes certain missions in addition to materials processing; these are by implication not included in COMM 1201, but the information in the data base does not provide enough detail to specifically exclude them.

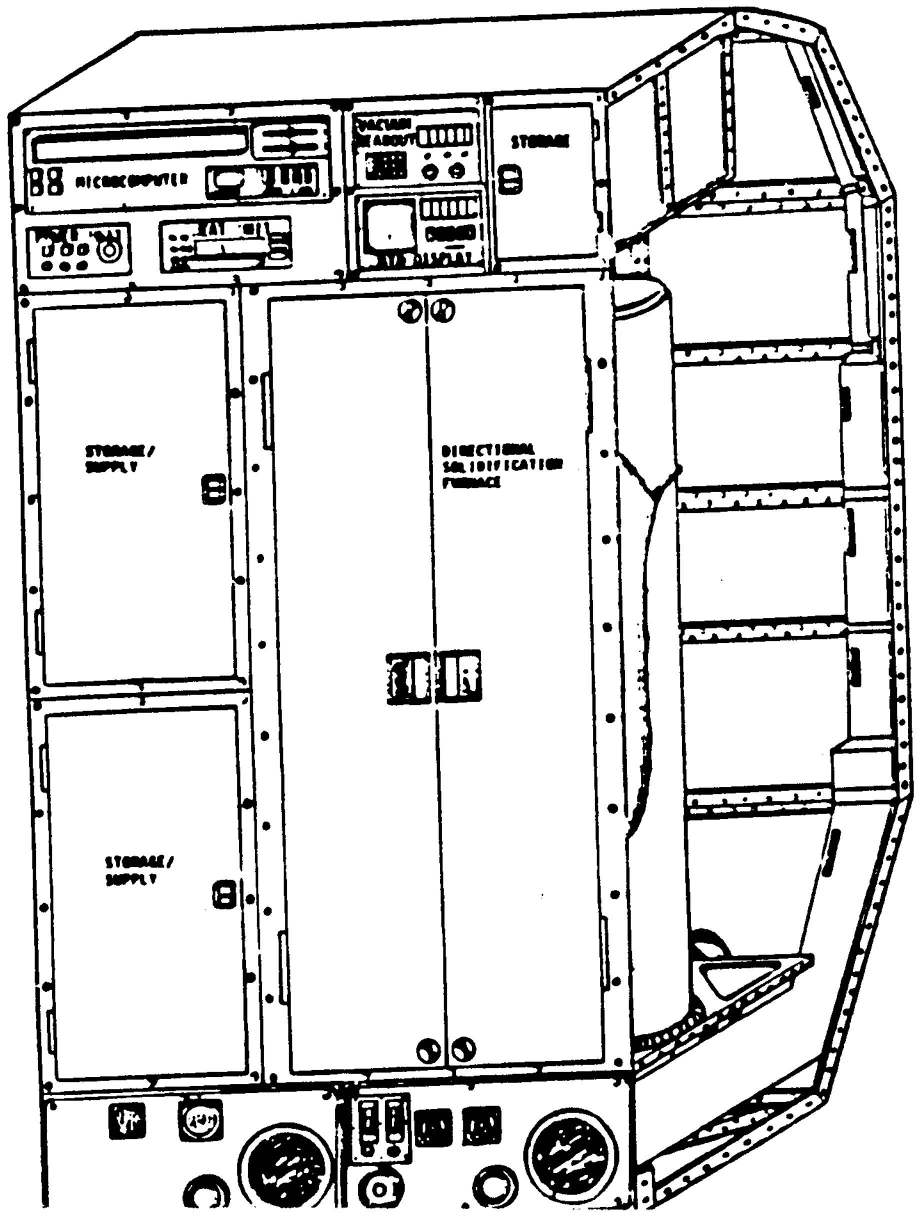
To design a laboratory, we found that we needed mission payload information at a much greater level of detail than contained in COMM 1201. We needed sizes, weights, data and power requirements, support equipment requirements, process operations details for estimating crew loading and the nature of potentially hazardous operations, resupply needs, and so forth. NASA anticipated this need and initiated, a few months before the start of the space station definition contracts, a study of a "Microgravity and Materials Processing Facility", MMPF. This study addresses the mission needs and requirements for materials processing R & D in depth and is our primary source of mission requirements data.

The MMPF study has identified more than 150 potential materials processing payloads and has characterized 30 in the detail we need for laboratory design. The 30 representative payloads were selected to cover the spectrum of scientific disciplines, kinds of users (academic, commercial, etc.), and maturity of development from exploratory research to commercial prototyping. Sizes range from about one cubic foot to about fifty, power levels from a few watts to fifteen kilowatts, and support needs from none to extensive. Data rate requirements, except for video, are uniformly modest, usually less than one megabit/sec per payload. The lab will accommodate about eight to fifteen such payloads, depending on size; the set of 30 thus allows alternative payload sets to be compiled to test the adequacy of accommodations.

Table 2 - MMPF Payloads

Discipline	Experiment
Bioprocessing	
	Continuous Flow Electrophoresis...........
	Isoelectric Focusing......................
	Protein Crystal Growth....................
	Collagen Processing.......................
Electronic Materials	
	Directional Solidification................
	Electroepitaxial Crystal Growth...........
	Vapor Phase Crystal Growth................
	Solution Crystal Growth...................
	Float Zone Crystal Growth.................
	Thin Film Crystal Growth..................
	Fluid Experiment System
	Vapor Crystal Growth System (FES/VCGS).
Glasses and Ceramics	
	Acoustic Containerless Processing.........
	Glass Fiber Pulling.......................
	High Temperature Glasses..................
Combustion	
	Droplet Burning...........................
	Solid Surface Burning.....................
	Premixed Gas Combustion...................
	Autoignition Studies......................
Fluids and Transport Phenomena	
	Cloud Formation Microphysics..............
	Free Surface Phenomena....................
	Critical Point Phenomena..................
	Thermophysical Properties.................
Metals and Alloys	
	Electromagnetic Containerless Processing.
	Solidification of Immiscible Alloys......
	Undercooling EM Effects...................
	Eutectic Alloy Solidification.............
	Foam Metals...............................
Polymers and Chemistry	
	Monodisperse Latex Spheres................
	Membrane Production.......................
	Transcrystallization in Thermoplastics.
	Zeolite Catalyst Production...............

Figure 8 DIRECTIONAL SOLIDIFICATION FURNACE



SPACE STATION

Figure 9 SOLUTION CRYSTAL GROWTH FACILITY

BOEING

TELEDYNE BROWN ENGINEERING

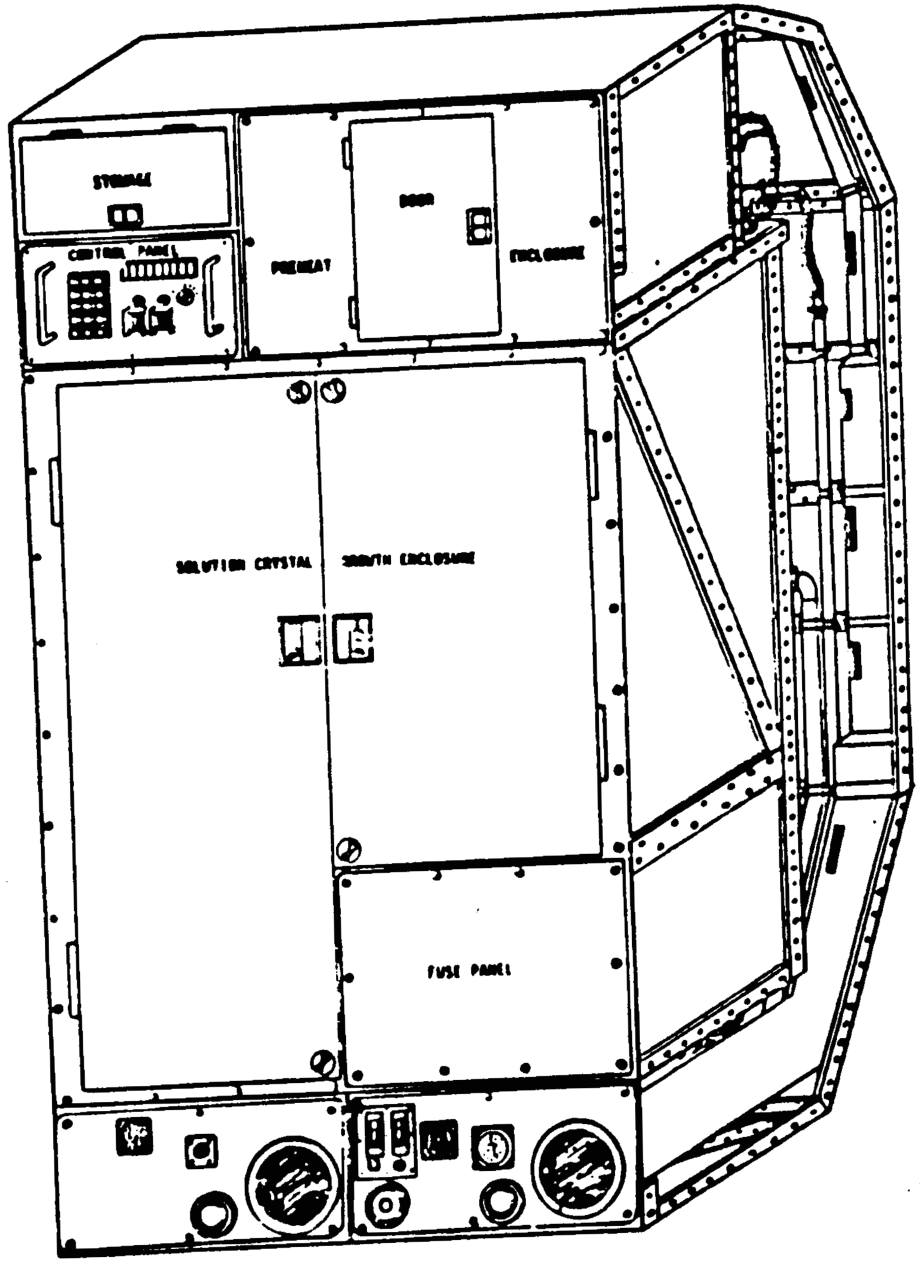


Table 3 EXPERIMENT EQUIPMENT

EQUIPMENT	VOLUME (M3)	Single Rack Equivalents SRE	Double Rack Equivalents DRE
acoustic containerless proces	1.36785	2.25	1.00
combustion tunnel	0.65880	1.00	0.50
directional solidification fu	0.53260	1.00	0.50
droplet combustion facility	0.65880	1.00	0.50
electroepitaxial crystal grow	0.84000	1.50	0.75
electromagnetic containerless	0.84000	1.50	0.75
electrophoresis facility	1.38[illegible]	2.25	1.00
free surface apparatus	0.25000	0.50	0.25
isothermal furnace	0.1[illegible]681	0.25	NA
Langmuir-Blodgett facility	0.0[illegible]600	0.25	NA
latex reactor system	1.[illegible]	2.00	1.00
protein crystal growth facili	0.[illegible]	1.50	0.75
solution crystal growth facil	1.68000	2.75	1.25
vapor crystal growth furnace	0.84000	1.50	0.75

Resupply is potentially critical because the cost of payload delivery to orbit by space shuttle exceeds $2000 per pound and the frequency of shuttle flights supporting the space station will probably be limited to, at most, eight per year.

We analyzed laboratory resources needs using an operational simulation technique. Efficient use of the lab within resource constraints presents a well-known operations research problem often called "job-shop scheduling". Most automated scheduling systems include algorithms for it. We had used a scheduling system called PROJECT/2 to analyze space construction projects with limited crew and equipment resources on the Space Operations Center (SOC) studies, and determined that the ARTEMIS system in use for the space station program could be similarly used. ARTEMIS includes extensive graphics capabilities useful for presentation of results.

The procedure was to build a data base of composite process operations ("experiment") schedules based on the functional flows (operations sequences) in the MMPF data base. Each step of each process was allocated crew and power resources. Process operations were defined as repeating endlessly so that constrained schedules could be compared against an unconstrained schedule where the number of repetitions in a given time period is as many as the duration of each process protocol will permit. A repetition included process or experiment preparation, cleanup and analysis as well as operation. We used a 90-day time period, and the unconstrained schedule permitted about 800 total process repetitions in that period. (The number per process varied from a few to dozens because of differences in process protocol durations.) In view of our earlier result that users will want to operate their equipment about 35% of the time on the average, we set our target capability at about 250 to 300 process repetitions, i.e. roughly 35% of 800.

Figure 10 shows a representative partial crew schedule for the unconstrained case, illustrating the level of detail of modeling. Figure 11 shows a power schedule resulting from resource loading the functional flow. Figure 12 shows the cumulative crew requirements with no crew constraints applied. Figure 13 is a graph of crew requirements with a constraint of three crew. Figure 14 shows a typical cumulative power usage result: a power constraint was not applied in this case.

The principal results of this analysis are obtained by applying constraints parametrically and examining schedule performance. Results for separate application of crew and power constraints are shown in Figures 15 and 16. The results are typical of a good constrained scheduling algorithm: rearrangement of the schedule accommodates the limits well up to a point; after that, performance suffers significantly.

These results were obtained for a set of eight processing facilities. Later in the space station study, the lab was increased

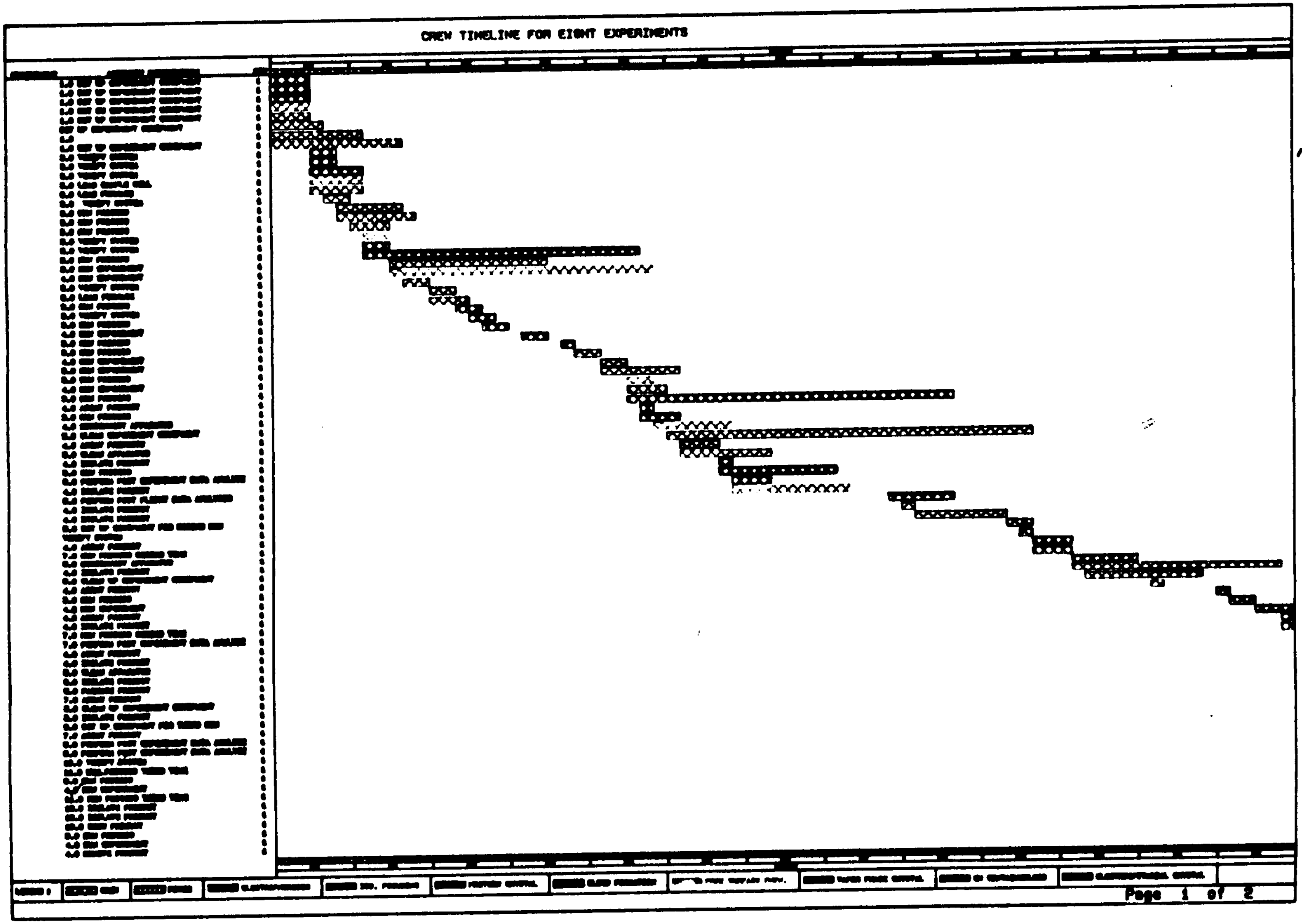


Figure 10 - Partial Crew Schedule For 8 Facilities

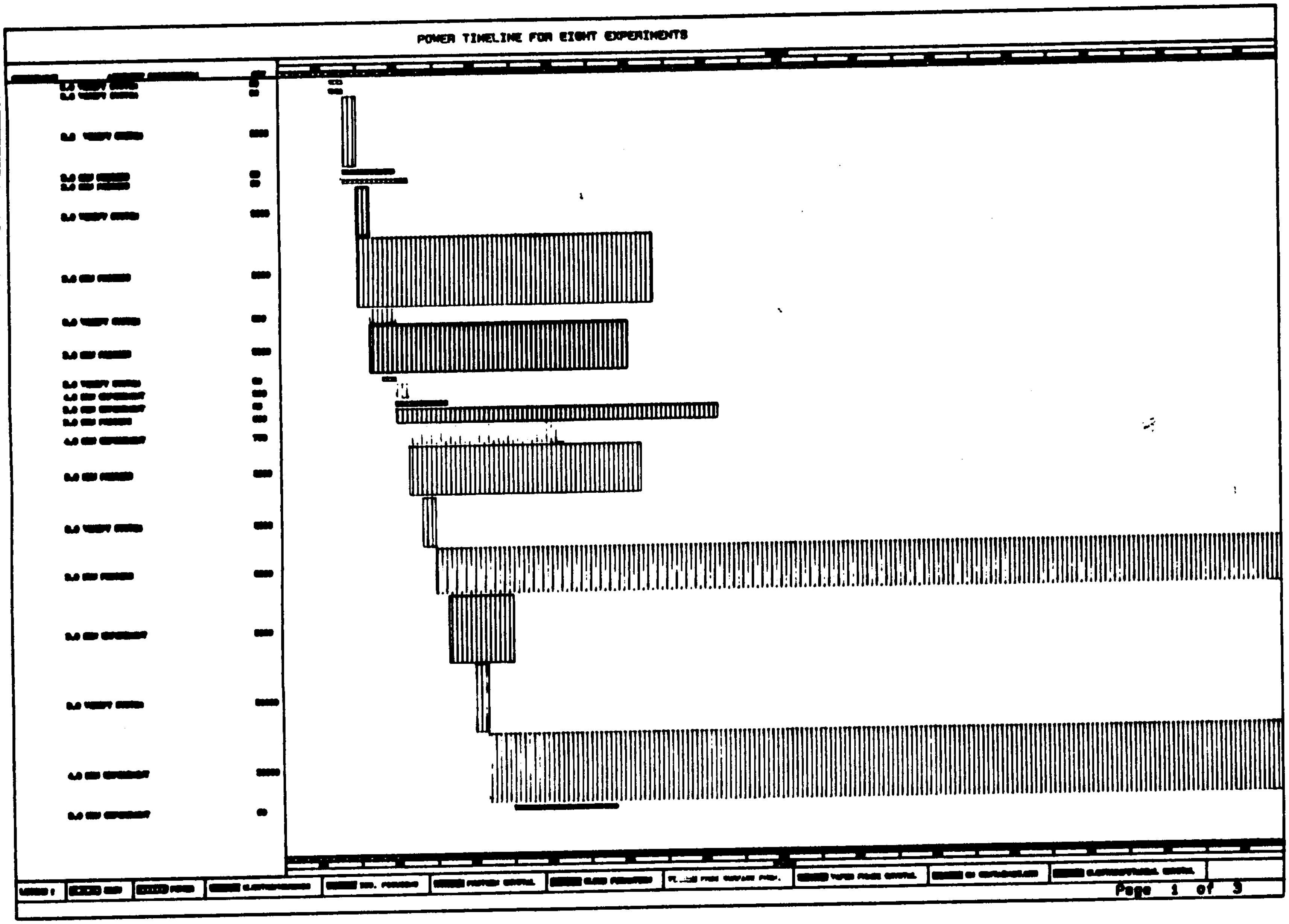


Figure 11 - Power Schedule for 8 Facilities

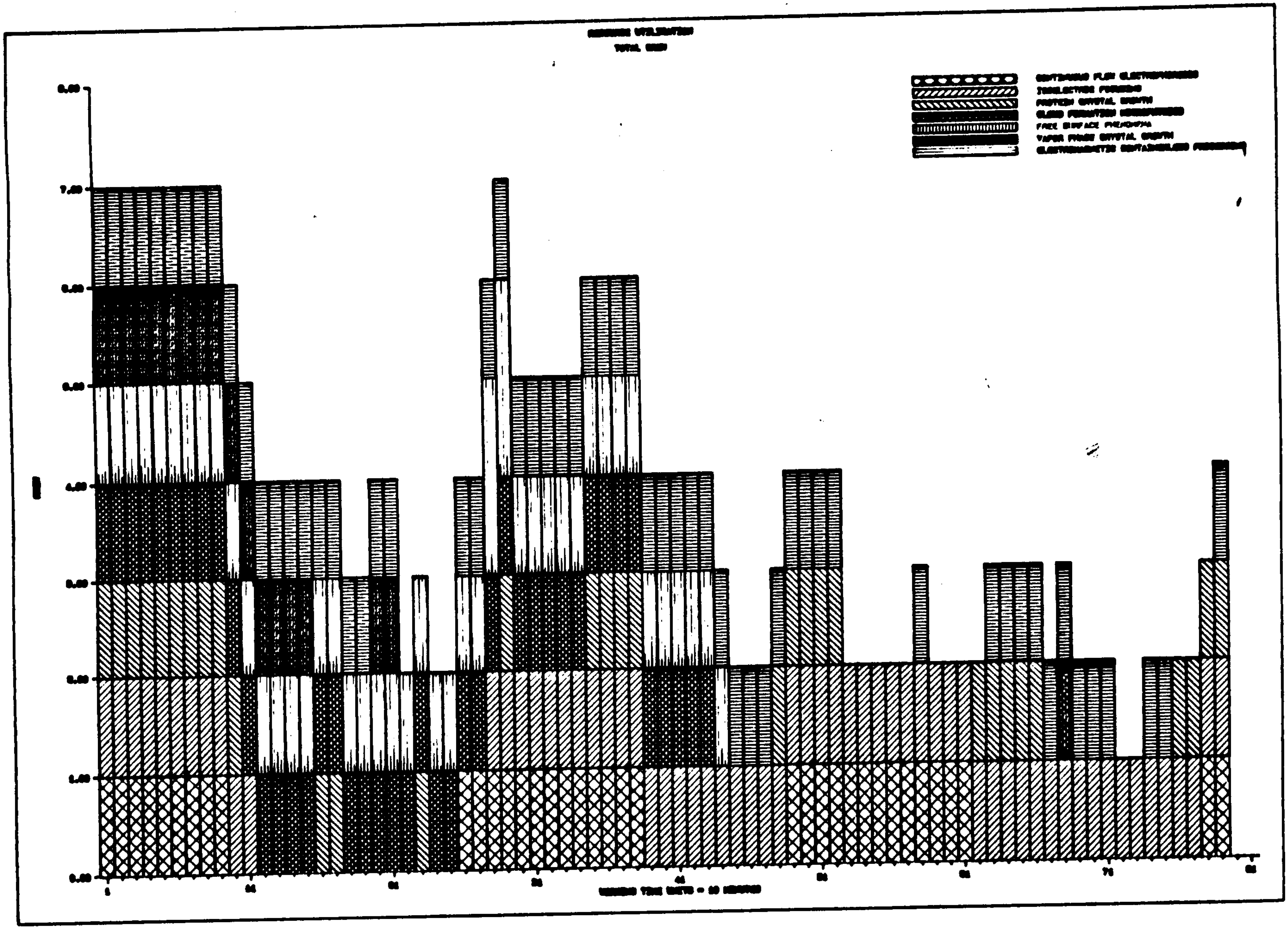


Figure 12 – Crew Requirements Without Constraints

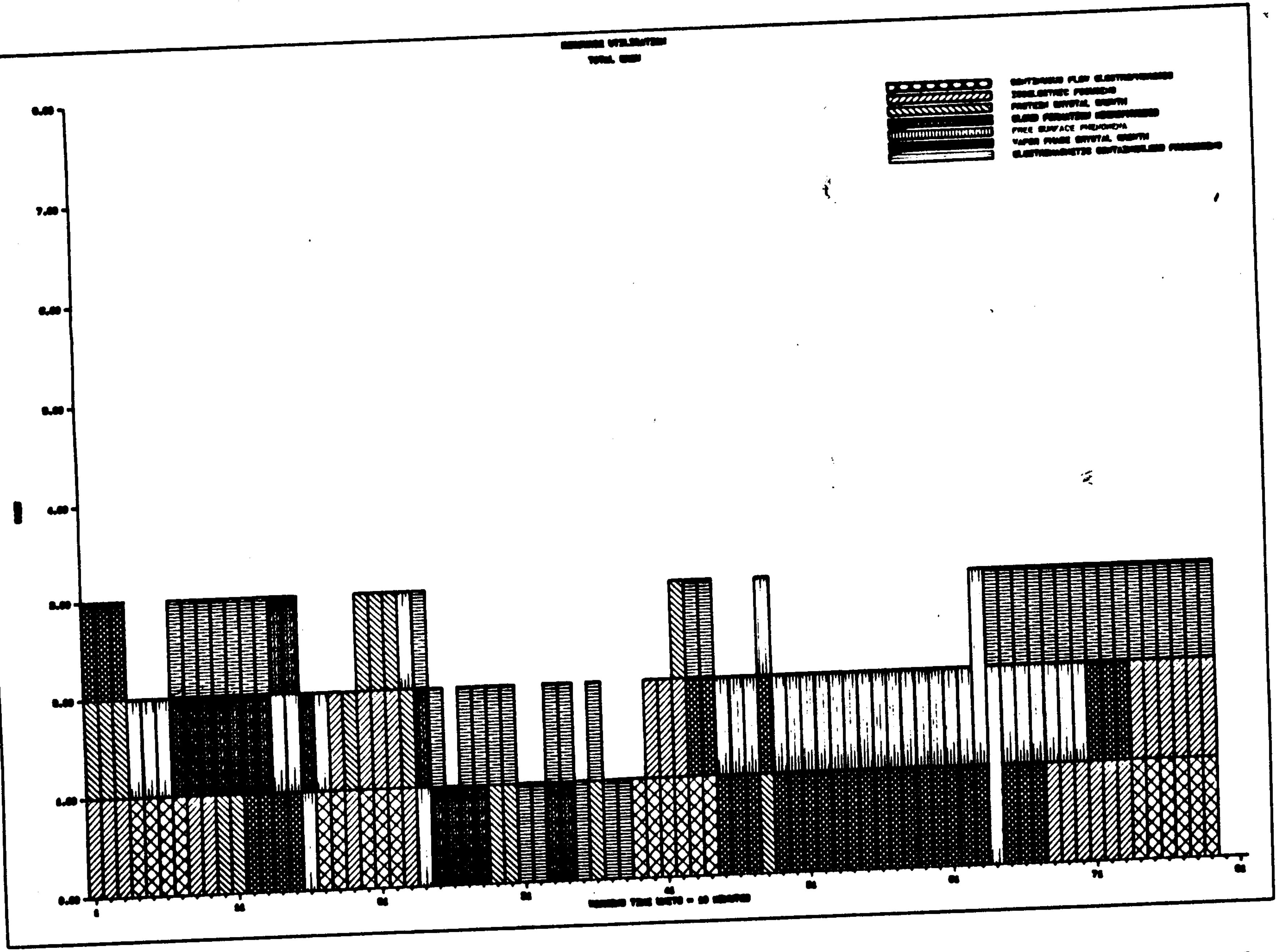


Figure 13 - Crew Requirements With Constraint

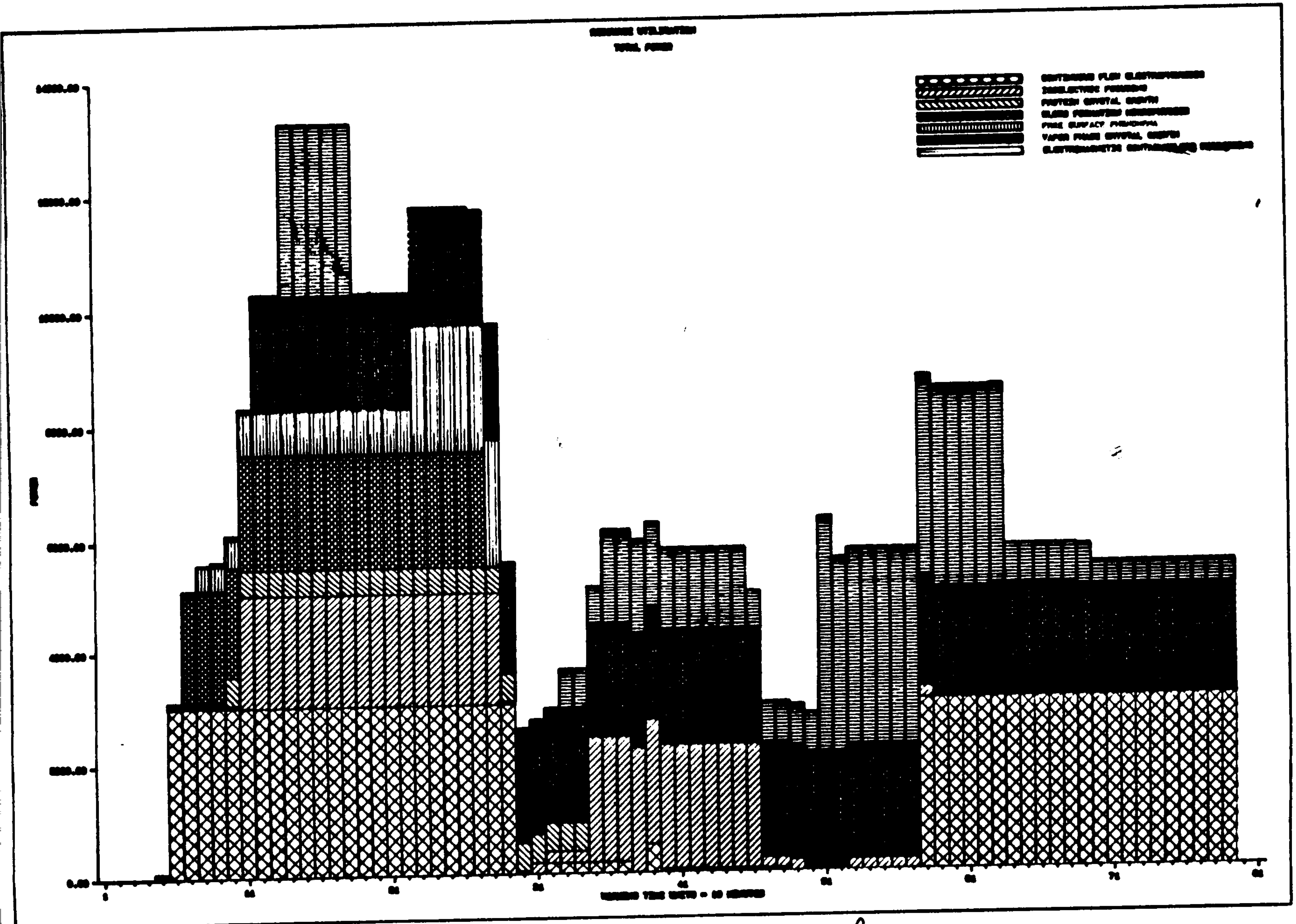


Figure 14 Typical Unconstrained Power Requirements Schedule

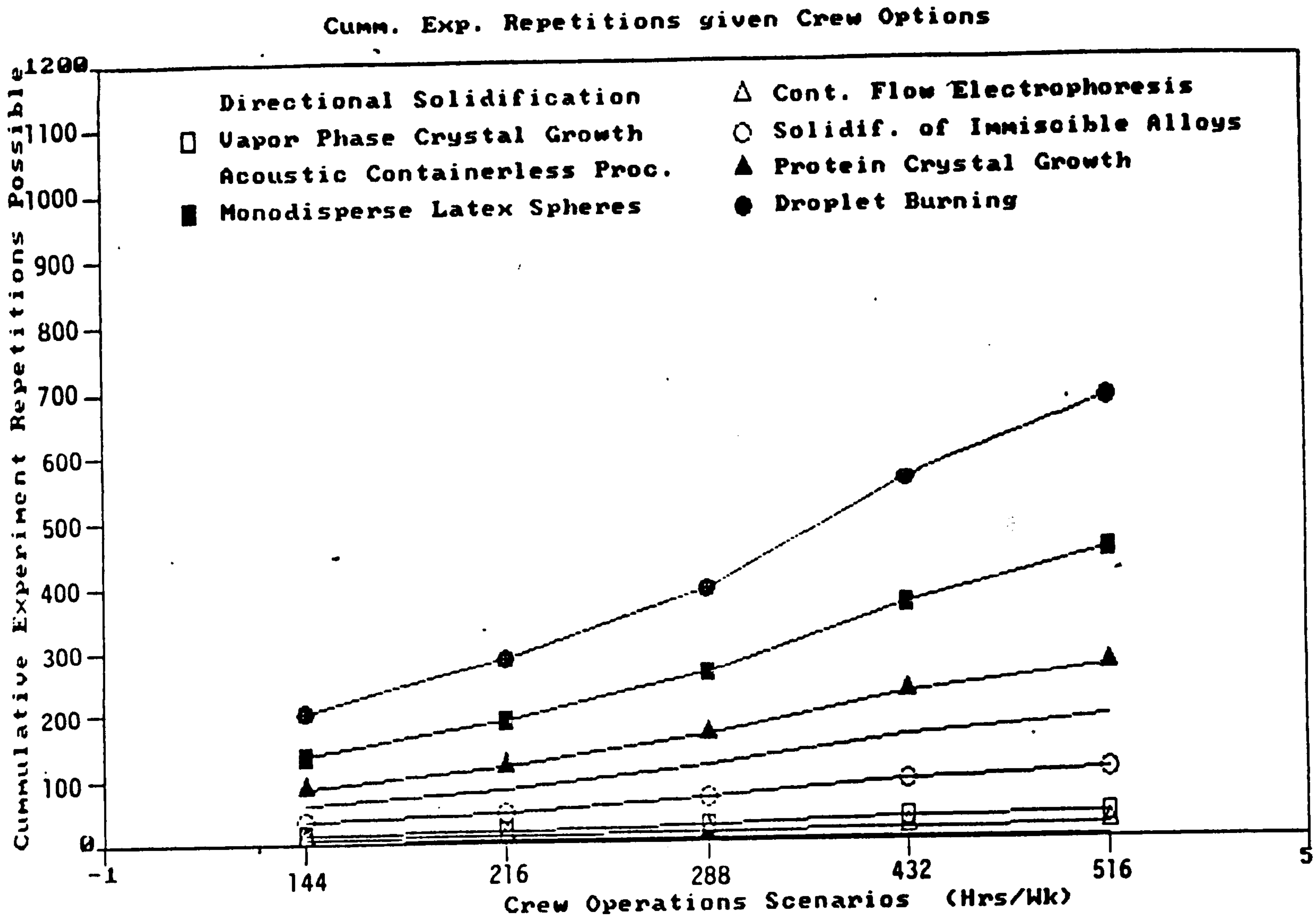

Cumm. Exp. Repetitions given Crew Options
Directional Solidification
Vapor Phase Crystal Growth
Acoustic Containerless Proc.
Monodisperse Latex Spheres
Cont. Flow Electrophoresis
Solidif. of Immiscible Alloys
Protein Crystal Growth
Droplet Burning
Cummulative Experiment Repetitions Possible
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-1
144
216
288
432
516
5
Crew Operations Scenarios (Hrs/Wk)

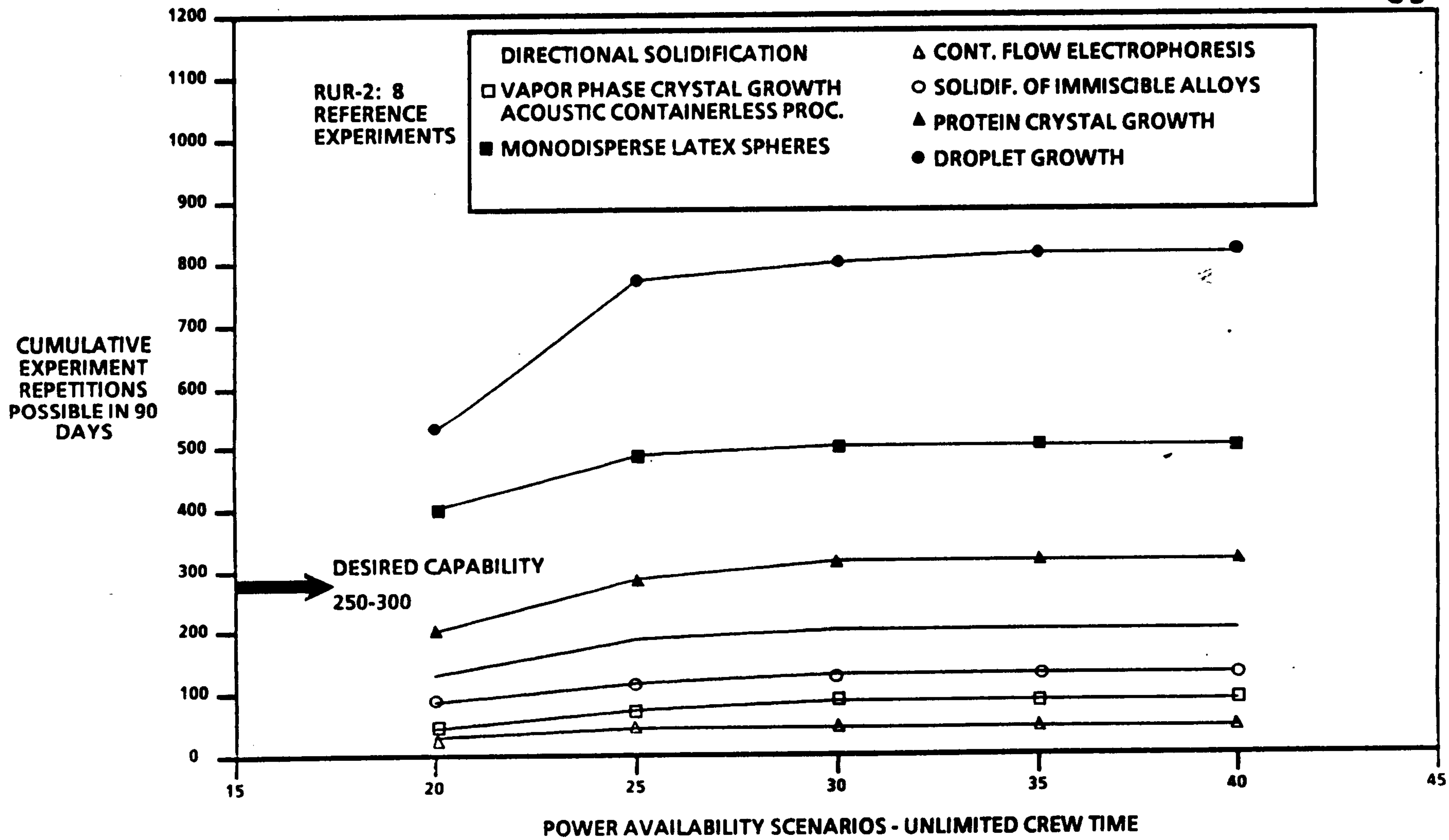
Figure 15

Figure 16

Cumulative Experiment Repititions Given Power Availability

SPACE STATION

BOEING



in size and fourteen facilities were baselined. We had learned enough "rule of thumb" behavoir of resources allocation to do most of the analyses by shortcut methods rather than full simulation: these were applied to the 14-facility case. A representative result is shown in Figure 17. We concluded that, for the 25%-35% utilization range, a crew of 4 to 6 for the lab would be ideal, but that the 2 to 3 we expect will be adequate. With only 2 to 3 crew, it is advisable to reduce on-orbit analysis of lab results to a minimum level, commensurate with ensuring that experiments and investigations are proceeding properly. This appears to have little effect on what characterization equipment is appropriate for the lab, but significant impact on how and how often it is used.

Power results for the 8-facility set are applicable to the set of 14, because crew availablility sets the power level. 20 to 25 kW of user power will permit lab operations with relatively little constraint effect due to power limits. This is true because the desired utilization level for a process is only about 35% and because significant parts of a process flow for a high-power payload do not involve operations at high power. Therefore, even though only one 15-kW furnace can be operated at one time with a 25-kW power constraint (there are typically three on board), this limitation is easy to schedule around.

As materials processing applications grow and mature, more user power will be needed. Production prototype equipment will have higher desired duty factors than the 25%-35% used to derive initial power requirements, and payloads needing more than 15 kW are expected. Some estimates have run as high as 60 kw for one payload. A representative power growth forecast is presented in Figure 18.

There is an important software implication here: efficient use of space station resources for the lab means that a real-time scheduler for lab operations will be needed; it should be an on-board capability easy and practical for the crew to use; the scheduler-controller needs a "look-ahead" feature so that experiment power, once enabled, is available to the user for the duration of his process run; a mature job-shop scheduler algorithm should be lifted from an existing project planning software package and adapted to space station use.

Estimated resupply requirements for the space station lab are summarized in Table 4 for a range of crew hours available (10 hours/day is approximately one crew member; final rules for scheduling crew time are not established). These values include a nominal allowance for facility and apparatus spares to cover repair and modification and for replacement and return of facilities and equipment as research and development programs are completed. The values do not include logistics overhead such as packaging and logistics modules or pallets (the rack provides the packaging for rack-mounted equipment). They also do not include allowances for space station resupply or for the international laboratories planned as part of the space station.

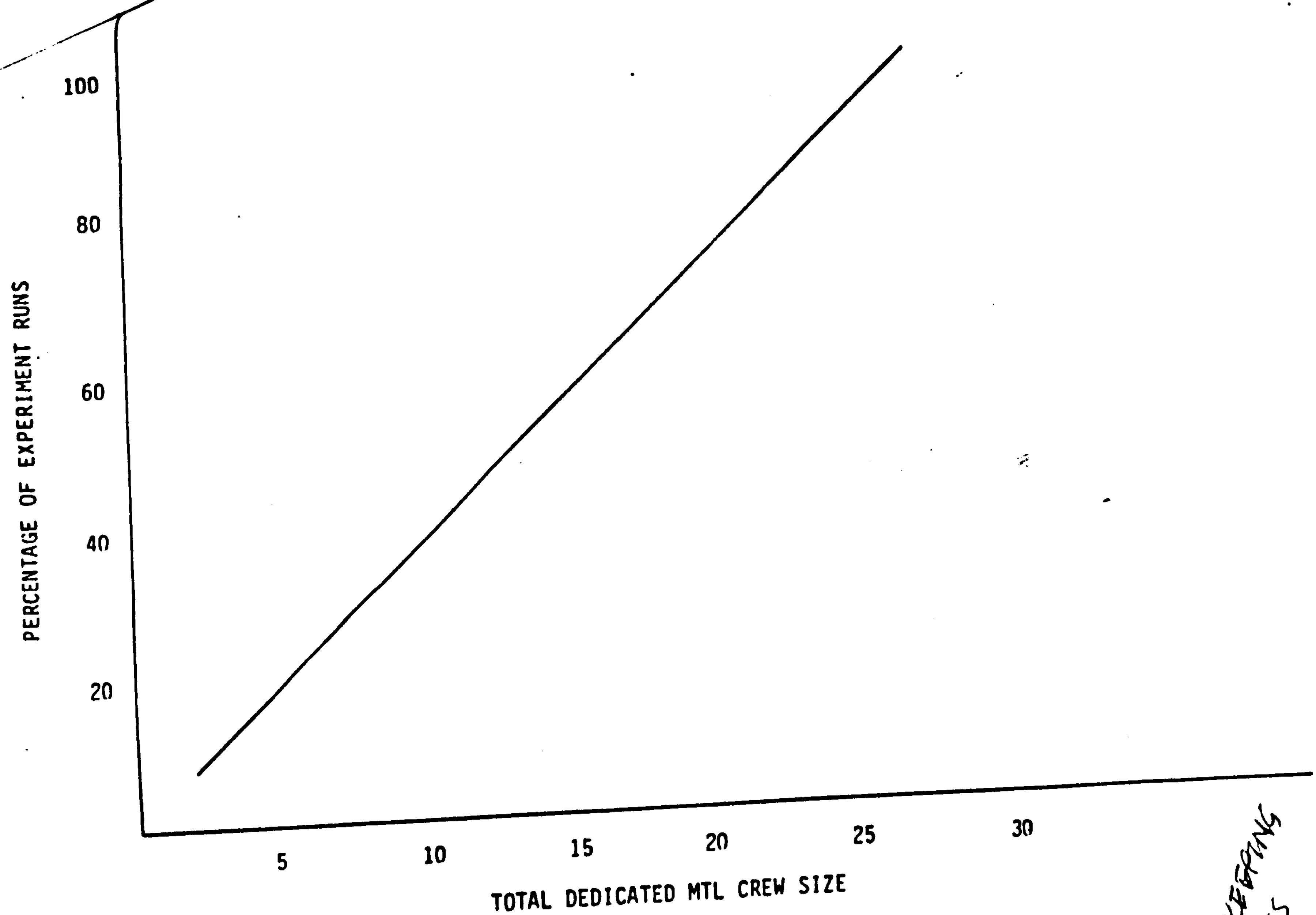
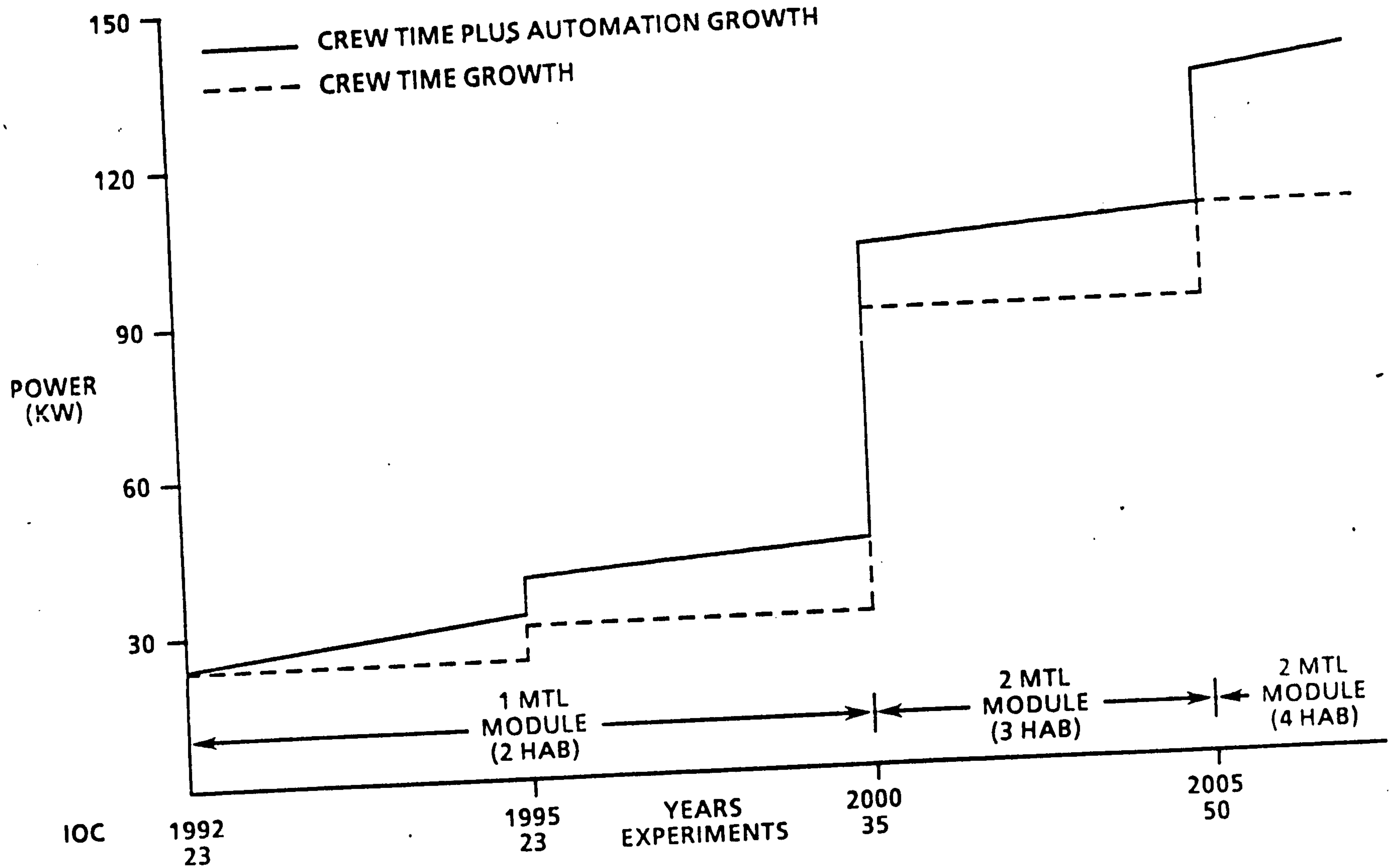


FIGURE 17 MTL CREW SIZE IMPACT ON EXPERIMENT OPERATIONS – 14 Experimental Facilities

HOUSEKEEPING SOVIETS

Fig. 18 USER POWER REQUIREMENT PROJECTION



T. 4

Resupply Table will use
MSFC synthesized Logistics
Requirements

Laboratory Configuration and Outfitting

The size of the laboratory module, illustrated in Figure 19, is dictated by the space shuttle payload bay and the operational requirement to carry a docking module along with the space station elements being delivered, so that the shuttle can dock to the space station.

A number of interior arrangements for the module were analyzed, with objectives of achieving a simple practical design while providing as much useful payload volume as possible consistent with crew workspace requirements. A further constraint on the design was to maintain payload accommodations commonality with the international modules so that a payload may be assigned to any of the lab modules present at the station. This feature offers great flexibility to mission and operations planners and enhances the overall utility of the station. The internal arrangements of the U. S., European, and Japanese modules are similar, but the diameters are different, with the international modules having an internal diameter about ten inches smaller than the 166" planned for the U. S. module.

The principal arrangement options evaluated were "horizontal", as depicted in Figure 20, and "vertical", with transverse circular floors dividing the module into five compartments. The horizontal arrangement was selected as better suited to a materials processing lab. It is also the arrangement for the international modules as well as being the preferred arrangement for a habitat. In space, of course, the terms "vertical" and "horizontal" refer only to visual orientation within the module and do not denote up or down. A representative module cross-section is shown in Figure 21. A representative allocation of interior volume to subsystems, equipment, and lab facilities is shown in Figure 22, illustrating that the lab interior must accommodate space station equipment and subsystems necessary to make the lab habitable, in addition to equipment and facilities that serve laboratory functions. Since the space station may consist of only two modules when initially manned, the lab must also include provisions (labeled "safe haven") to serve as an emergency habitat in the event the main habitat becomes unusable.

Standard "double" rack dimensions are shown in Figure 23. Two options are shown, the shorter compatible with the smaller diameter international modules and the larger reserved for certain U. S. module uses such as in the habitat. Most of the facilities and equipment will be accommodated in racks of the size shown, but a "single" rack of about half this width will also be available. The "single" and "double" designations are derived from the Spacelab; although the space station racks are a different shape than those for Spacelab, drawer-size Spacelab equipment will fit into these racks. The single rack accommodates the MIL-STD-189 rack drawer size.

Similarity among the four U. S. space station modules (one hab, one lab, and two logistics) has led to a design for a common

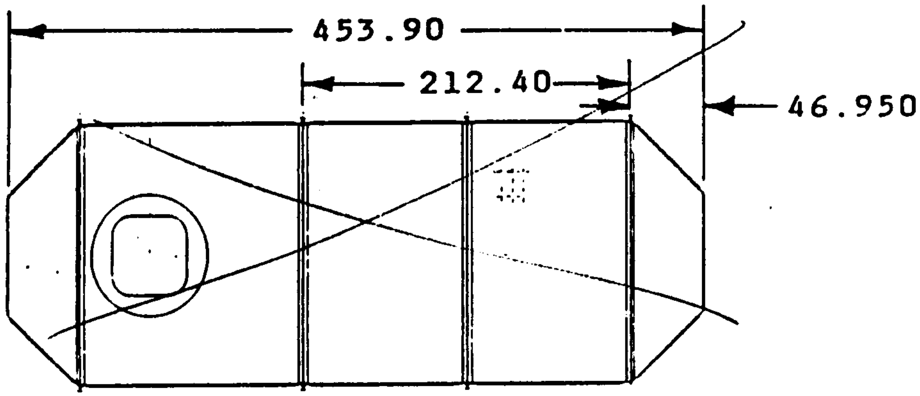
SPACE STATION

Figure 19

Module ~~Length Status~~ Dimensions

AS OF 2-21-86 SSCB

BOEING



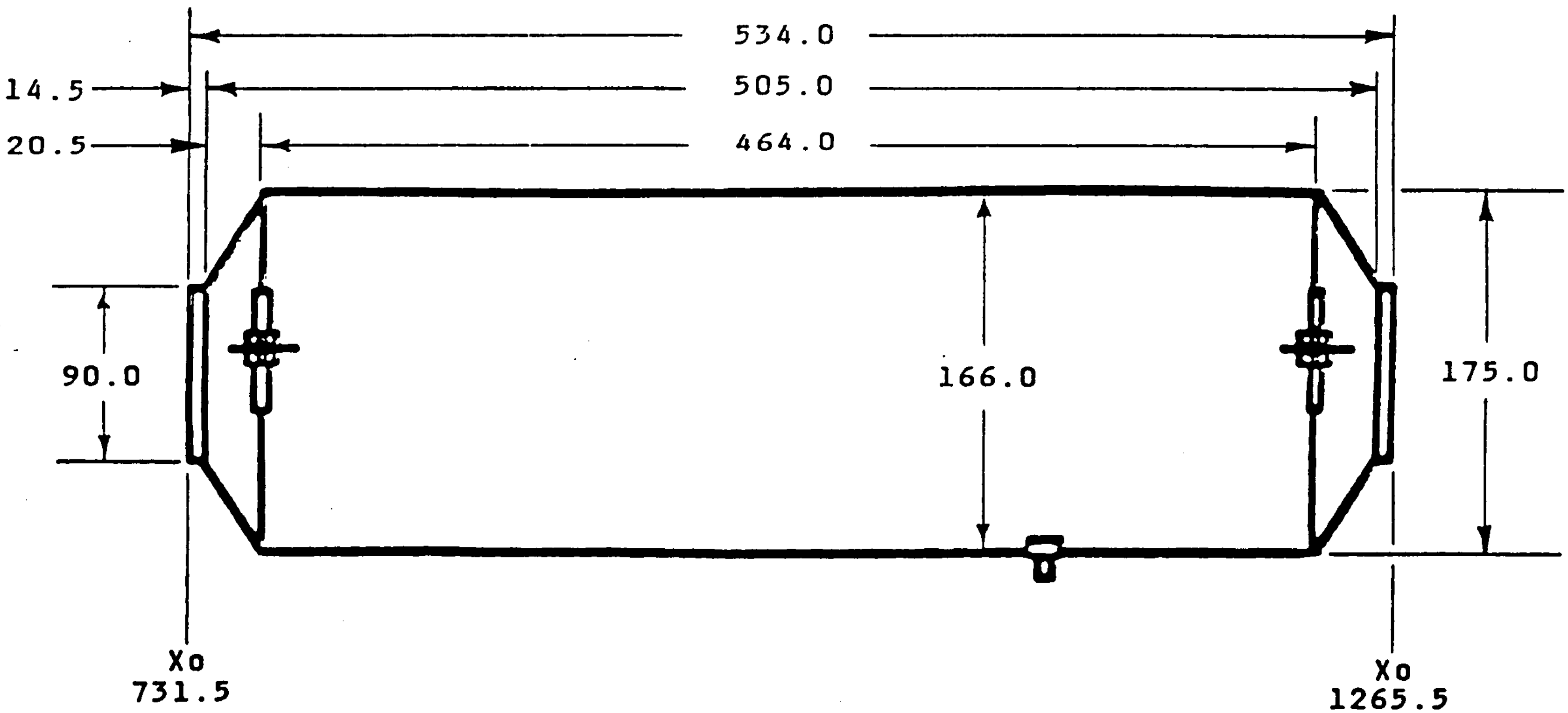


Figure 20 Manufacturing and Technology Laboratory - Typical Horizontal Arrangement

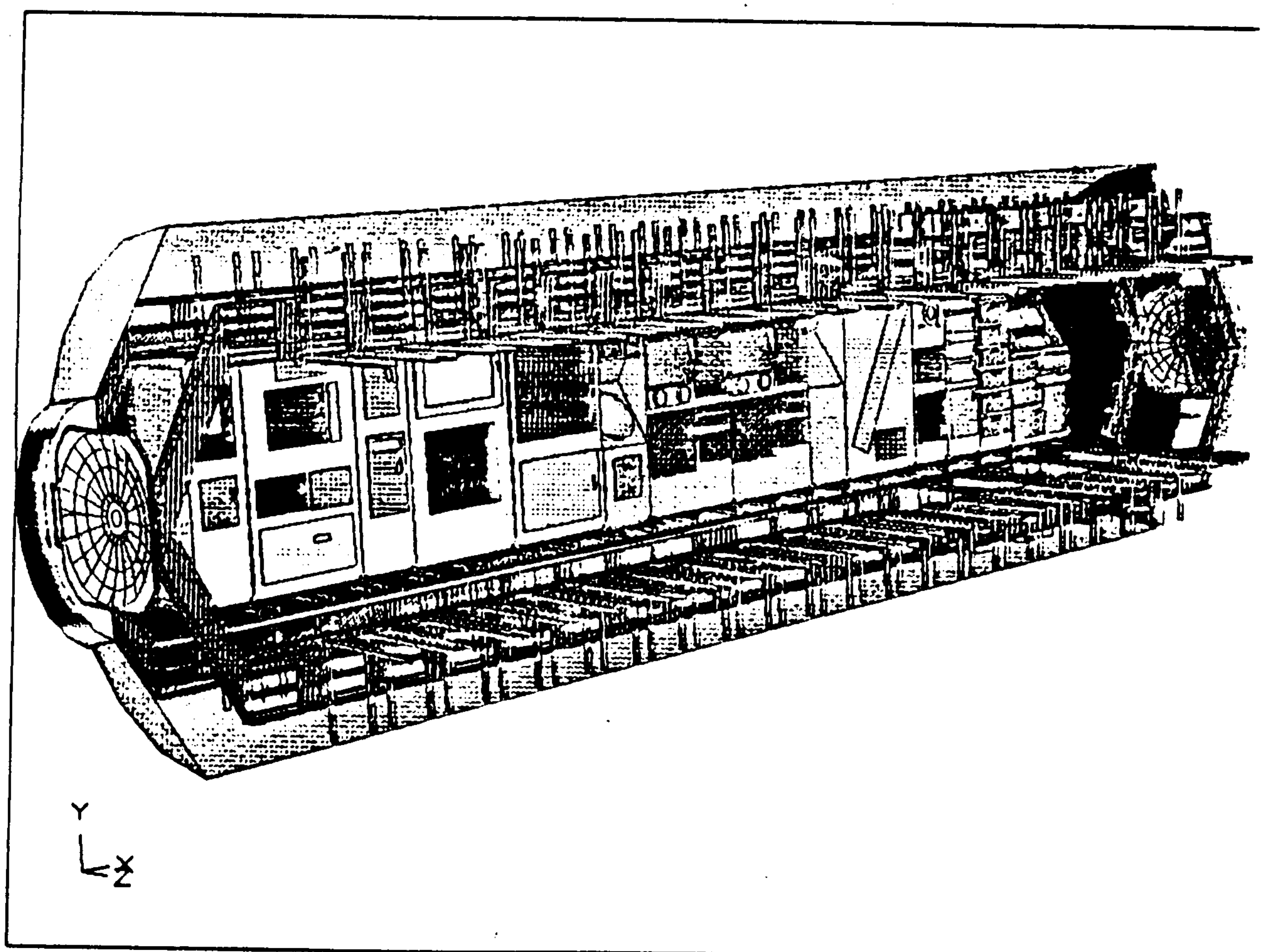
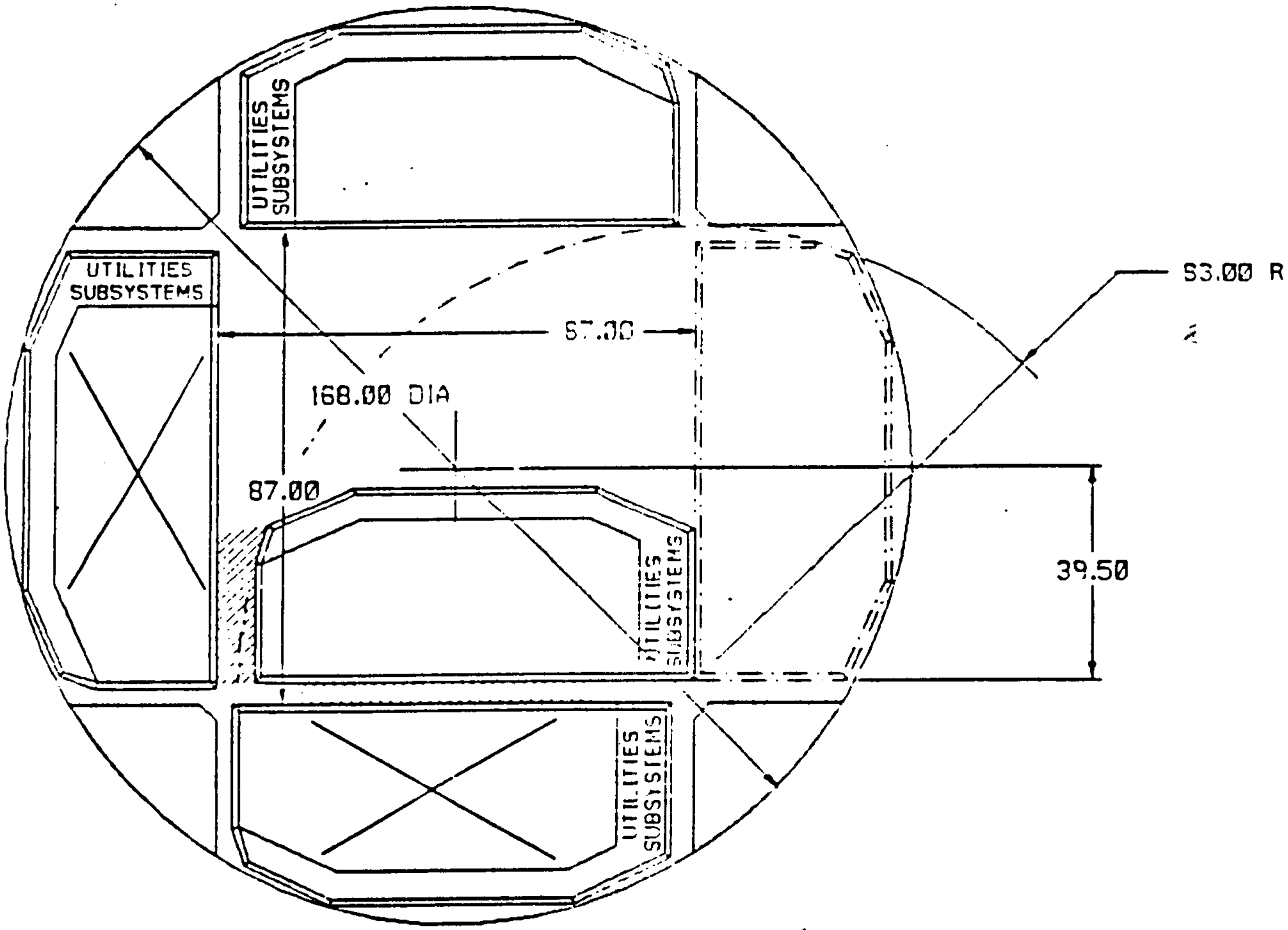


Figure 21 - Typical Module Cross Section

~~Equipment Access — Horizontal~~



LIMITED ACCESSIBILITY TO TOP AND FACE OF RACK, IF PASSAGEWAY IS TO BE PRESERVED

IMPEDES USE OF 1 – 2 ADJACENT RACKS

Figure 22

U. S. Laboratory Layout

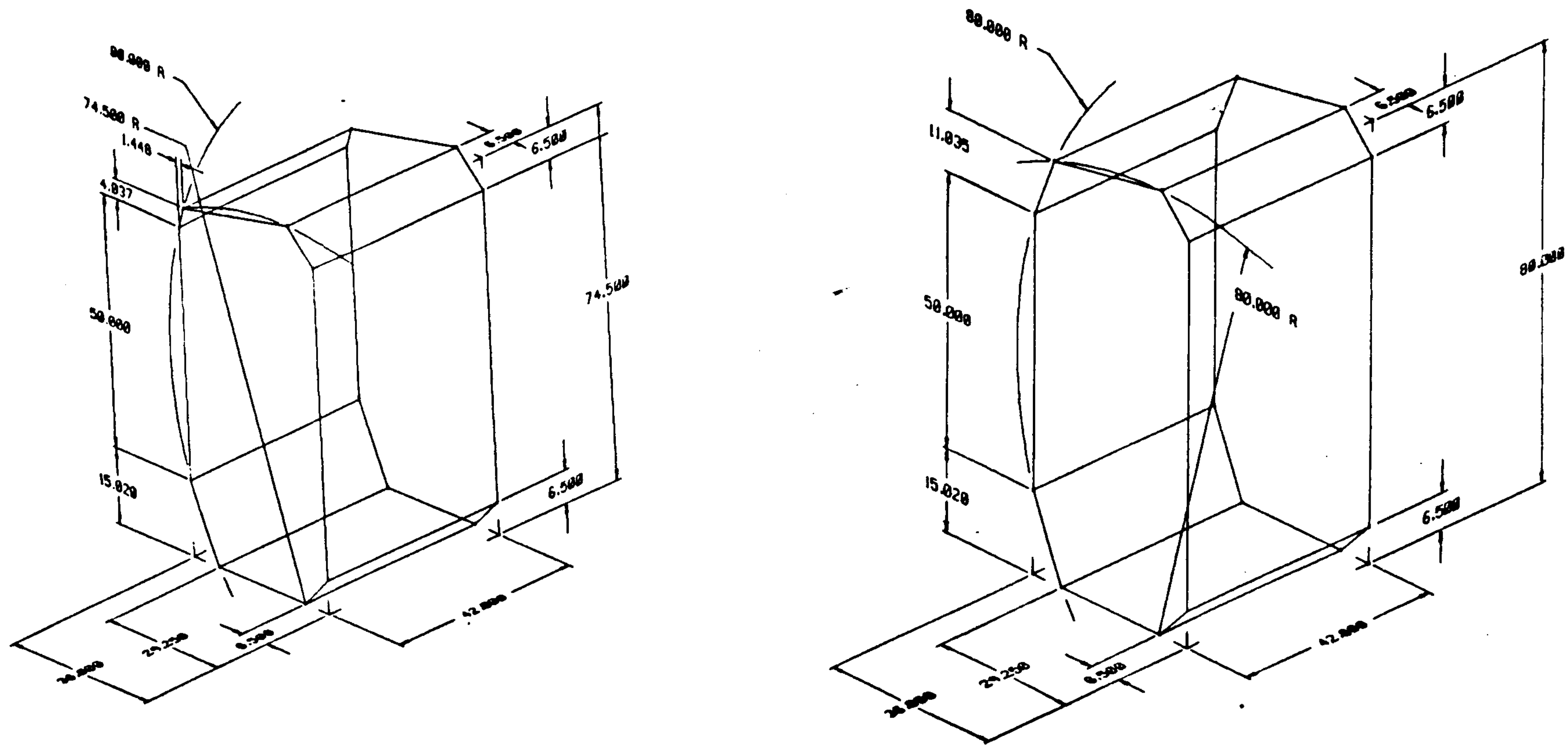
WP-01

CEILING	C & T	C & T	C & T	CM S/S SPARES	DMS	THC	AR	TCS	CM S/S SPARES	CM S/S SPARES	EPDS
WALL	ATTACHED PAYLOAD CONTROL	INSTRUM STOWAGE	INSTRUM STOWAGE	REFRIG & FREEZER	SUPPLIES, CHEMICAL STORAGE		GLOVEBOX	SOLUTION CRYSTAL GROWTH	ELECTRO-KINETIC FACILITIES	COMBUST FACILITIES	ACOUSTIC CONTAIN FACILITIES
FLOOR	EPDS	MTL S/S SPARES	SKIP RESUPPLY STOWAGE	SKIP RESUPPLY STOWAGE	SAFE HAVEN	AVIONICS AIR	HAZARD WASTE	EMER-GENCY SHOWER	ULTRA PURE H_2O	PROCESS FLUIDS	CATEGORY 5 STOWAGE
WALL	X-RAY FACILITIES	CATEGORY 5 STOWAGE	LATEX REACTOR	CAMERAS FILM, MEDIA	WORK BENCH	SURF & LANG-MUIR	VAPOR/PROTEIN CRYSTAL GROWTH	EMAG CONTAIN	ELECTRO-EPITAXY CRYSTAL	ADDTL FURNACES	MPAC

END CONE:
3 DR SKIP
RESUPPLY
AND
1 DR SAFE
HAVEN

Figure 23 Standard Rack Dimensions

74½" and 80" Double Racks



module that incorporates features and equipment common to these modules. Determination of what is common is incomplete, but in any case the concept of outfitting derives from the common module approach, where a contractor responsible for a particular end-use module is to receive a common module which he will outfit with the equipment unique to his particular module and its purpose.

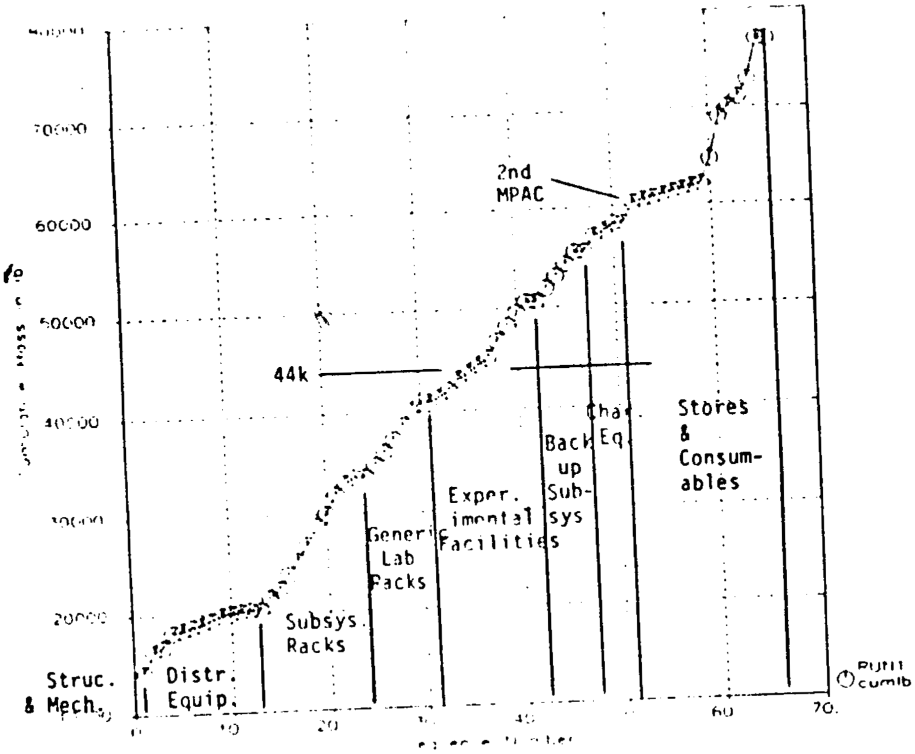
The preliminary design effort put into efficient utilization of the lab's interior volume was successful enough that the fully outfitted lab is too massive to launch in the space shuttle. Consequently, some of the outfitting will be done on orbit with equipment delivered on later flights. Estimates of shuttle payload capability to the space station range from about 44,000 to about 55,000 pounds of laboratory mass, depending on the delivery altitude, the shuttle configuration used, and the mass of other payload chargeables on the delivery flight. A fully outfitted lab including stored items and consumables will approach 75,000 lb. mass.

The strategy for outfitting concerns what to install on the ground and what to outfit on orbit. It gives top priority to subsystems and utility distribution that must be integrated and checked out to have a functional module and next, also very important, priority to similar lab systems that must be added to have a functional laboratory. Further, the strategy strives for initial mission capability for the lab as launched, adding more mission equipment, stores and consumables by on-orbit outfitting. Since the initial lab operations will be conducted before the habitat is added, while the station is manned only with the shuttle orbiter present (i.e. man-tended), stores and consumables for safe haven operations can be deferred to later on-orbit outfitting.

Outfitting sequence mass summaries based on this strategy are shown in Figure 24. At the lower end of the shuttle capability range, initial mission capability is obtained only by deferring certain redundant subsystems. At the upper end, initial mission capability is readily obtained.

Summary

Space station definition studies conducted for NASA-MSFC have defined the characteristics, mission capabilities, operational features, and design approaches for the U. S. space station laboratory. We have found that the space station laboratory can indeed be designed to usher in the promised new and highly productive era of microgravity research and commercial development.



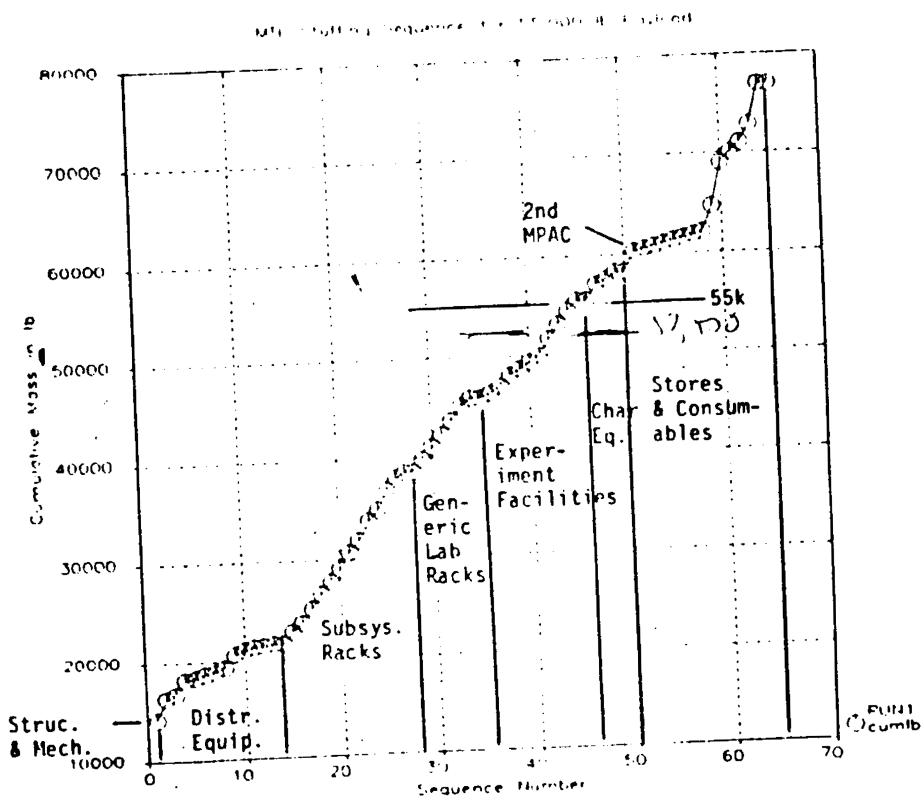


Figure 24 - Outfitting Mass Sequence For 44,000 lb and 55,000 lb Shuttle Payloads